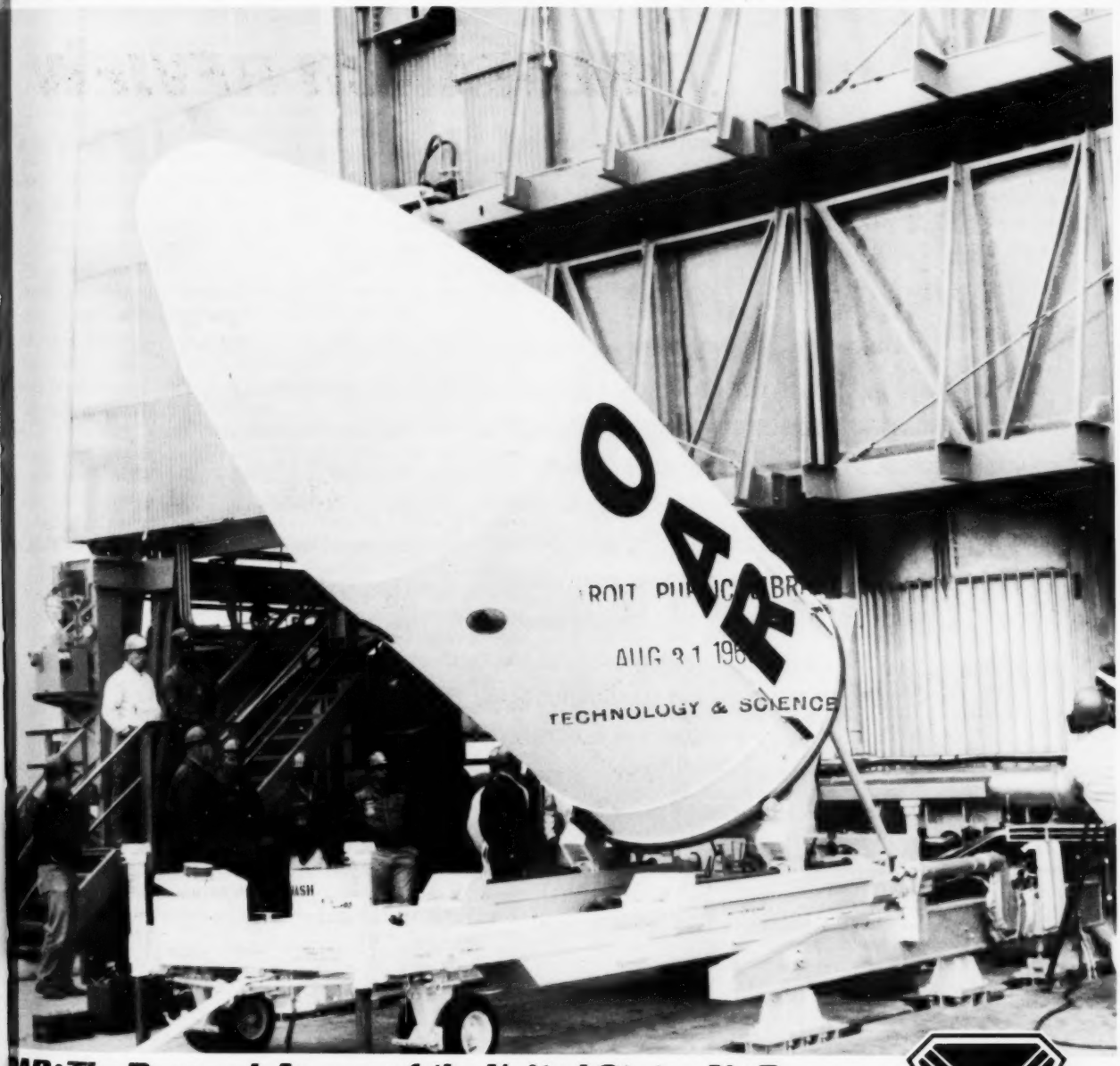
# OAR RESEARCH REVIEW

OFFICE OF AEROSPACE RESEARCH ★ UNITED STATES AIR FORCE

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VOLUME VII NUMBER 4 APRIL 1968


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**ON THE COVER:**

Shown is a newly designed heat shield containing two OAR research satellites, the OV1-13 and OV1-14, which were successfully launched from Vandenberg AFB, California, on 5 April 1968. These two satellites, launched aboard and ejected from an Atlas booster, contain seven AFCRL radiation experiments and an ARL CdS solar-cell experiment, as well as other materials-effects and radiation experiments from non-OAR organizations. Now in orbit, the OV1-13 and OV1-14 research satellites will remain operative for at least one year.

**OARRP 80-1**

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JACOB SEIDEN *Editor*

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# DOES THE PROTON HAVE AN INTERNAL STRUCTURE?

**DR. A. O. BARUT**
**Professor of Physics, University of Colorado**

The proton is the lightest of all fundamental particles that carry a nucleon number different from zero. The nucleon number N is equal to 1 for the proton and the neutron, 2 for the deuteron, and so on for the higher nuclei, but zero for photons, electrons and mesons; for the antiproton N=-1, etc. The sum of the nucleon numbers in any reaction is believed to be absolutely conserved. This accounts for the stability of matter. For, although heavier baryons can be unstable, the lightest one, the proton, must then be absolutely stable*. The proton is thus a good candidate for an elementary particle. Yet this fact does not exclude the possibility that the proton has an internal structure. For example, the ground state of the hydrogen atom (H-atom) is absolutely stable, unless it is violently hit and broken into pieces (dissociation). Can we in the same way eventually "dissociate" the proton? And, if so, what are its constituents and excited states?

These are perhaps the most fundamental questions concerning the strongly interacting "elementary" particles. It should be considered a sign of progress that physicists today can supply some *quantitative* answers to these old questions about the nature and indivisibility of matter. And, if history repeats itself, we would be at the threshold of uncovering a new organization of matter that is reminiscent of, and indeed continues, the hierarchy of atomic and nuclear structures.

One may argue that, at distances of less than $10^{-13}$ cm, the principles of relativity and quantum mechanics would preclude giving a meaning to the spatial distribution of matter inside the proton. In fact, according to one of the main current approaches to the structure of the strongly interacting particles, the so-called "bootstrap" method, all strongly interacting particles are "composed" of each other, and the self-consistency of this idea within the general principles of quantum theory would result in the observed discrete mass spectrum of the particles. The answer to this argument against a definitive internal structure of the proton is that quantum theory gives us the means of talking about the internal or composite structure of a system in other ways than in terms of a purely space-time distribution of matter. We can, namely, describe the composite structure of a system in terms of the behavior of the observed global quantum numbers as well.

Experimentally, we study the structure of any quantum system by probing it with external agents, $\gamma$ rays, electrons, and other particles. These external interactions reveal to us the internal structure of the system in terms of excited-state resonances or by knocking out (producing) the constituents. Clearly, if a particle is treated as elementary, then any such resonance structure of symmetry observed in their interactions must be attributed to the forces between them. It is therefore essential for the problem of nucleon-nucleon or meson-nucleon interactions, whether we attribute the multitude of complex observed phenomena to the complexity of the forces or to the complexity of the internal structure. To clarify this point

**The estimated lifetime of the proton exceeds that of the universe.*

we go back again to the analogy with the H-atom: if we did not know the structure of the H-atom, and if we treated the H-atom as an elementary particle (and its excited states as other distinct elementary particles), then we would have to invoke very complicated forces to explain the observed resonances. Thus, for both theory and experiment, it is essential to face the question of the internal structure of fundamental particles. And, in order to answer the question of proton structure, we must construct a definite model to explain quantitatively the properties of nucleons, just as the model of the H-atom explained atomic properties. These nucleon properties are: (1) quantum numbers (charge, spin, etc.) and multiplicity of states; (2) magnetic moments; (3) mass spectrum; (4) form factors (essentially Fourier transforms of the charge, magnetic moment distribution); (5) decay rates of excited states (i.e., width of the resonances); and (6) scattering amplitudes of various reactions. There is now considerable accurate experimental information for all of these properties, in particular, the form factor, and consequently the "size" measurement of the proton by means of the powerful new electron accelerators. In fact, one can say that the field of *nucleon structure* began with the measurement of form factors at Stanford and Cornell in the late fifties and early sixties.

It is remarkable that the analogy between the proton and the H-atom mentioned above goes much deeper, and that these two vastly remote structures show qualitatively the same behavior concerning the properties that we have listed above. In particular, there is evidence for a new quantum number n, exactly analogous to the principal quantum number of atomic physics. (See Table I.)

**Table I**

**A Comparison of the Structure of the H-Atom and that of the Proton**

| | H-Atom | Baryon Tower |
|---|---|---|
| Ground State | $J^P = \frac{1}{2}^+$ | $J^P = \frac{1}{2}^+$ |
| Excited States | $\|njm, \pm>$ | $\|njm, \pm>$ |
| Mass Spectrum | $M \cong M_{min} + a\frac{n^2-1}{n^2}$ | Similar |
| Form Factor of the Ground State | $G(t) \cong (1-at)^{-2}$ | $G(t) \cong (1-a't)^{-2}$ |
| Decay Rates to the Ground State | about exponential decrease with j | Similar |
| Scattering | Excitation of resonances in e-H scattering—structure in elastic cross section | Resonance structure in elastic $\pi$-p cross section |

Recognizing that the structure of nucleon interactions and the approximate broken symmetry is a property of the internal structure and not of the forces of interactions, we have carried out in the last two or three years, with the support of the Nuclear Physics Division of AFOSR, a program of research aiming at quantitative results of nucleon properties. It was necessary for this purpose to reformulate the atomic theory in terms of observed quantum numbers, rather than in terms of space-time wave functions. It is possible now to treat the H-atom (and its interactions) as a single composite system endowed with internal quantum numbers, without talking about the spatial wave function. The mathematical formalism rests heavily on some new group theoretical techniques, but still remains within the general principles of quantum dynamics. The use of group theory in this new version goes much beyond simple symmetry considerations and yields dynamical results as well. For this reason, the groups used have been called *dynamical groups*. In particular, the conformal group [in mathematical notation, the group 0 (4,2)] has proved itself to be really a universal group of physics, giving us the proper framework (that is, the set of the physical

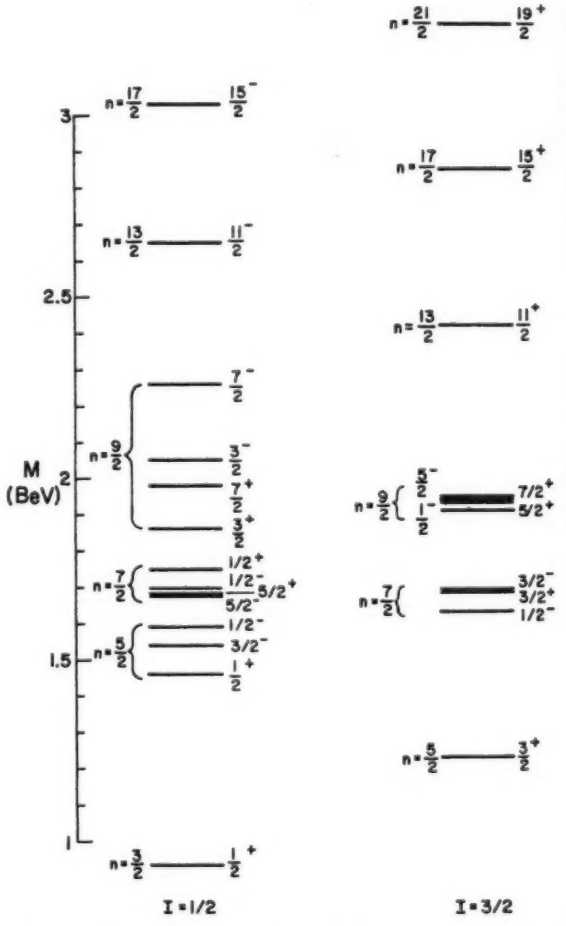


**Figure 1.—Empirical baryon states with baryon number N = 1, isotopic spin I = 1/2, and I = 3/2. Spin and parity of each level is given, as well as the new quantum number n. (Barut, A. O., *Phys. Letters, 26B*, 308, 1968)**

states of the system) not only for the H-atom and electromagnetic interactions, but also for the baryon and meson states of a definite class. It turns out that even the theory of leptons can be advantageously formulated in the same framework. For example, a reformulation of the Dirac theory of the electron-positron system reveals that particles and antiparticles may be distinguished by an internal quantum number n (the analog of the principal quantum number mentioned above), with both of them having positive energies. Thus a new alternative theory in the problem of nucleon structure is possible, complementing field theory and S-matrix theory. To assess its importance, we can say that, although field theory and S-matrix theory can be applied to the H-atom, they are poor alternatives to the Schrödinger theory. The question to be answered in the near future is whether a corresponding situation obtains for nucleons.

Within this framework, which starts from global quantum numbers, it is then possible to give completely relativistic calculations of the properties of composite quantum systems. Figure 1 shows some of the observed baryon levels and an assignment of the new quantum number n. In Figure 2, the experimental mass spectrum is compared with a simple theoretical model, which can be further refined. The assignment of meson quantum numbers and mass spectrum is shown in Figure 3.

The theory also explains the essential feature of the form factors, now measured up to very high energies

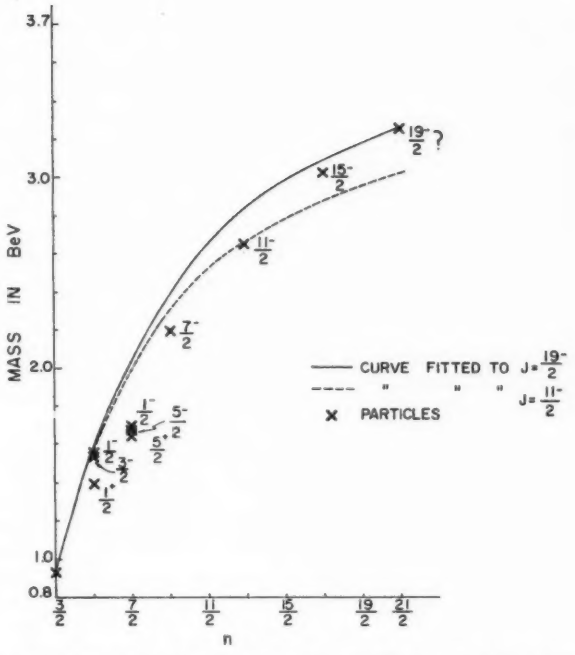


**Figure 2.—A theoretical mass formula based on a simple form of the theory is compared with the known particles for the I = 1/2, N = 1 levels. "Spin-orbit" splitting is not yet included. (Barut, A. O., D. Corrigan and H. Kleinert, *Phys. Rev. Lett., 20,* 367, 1968)**

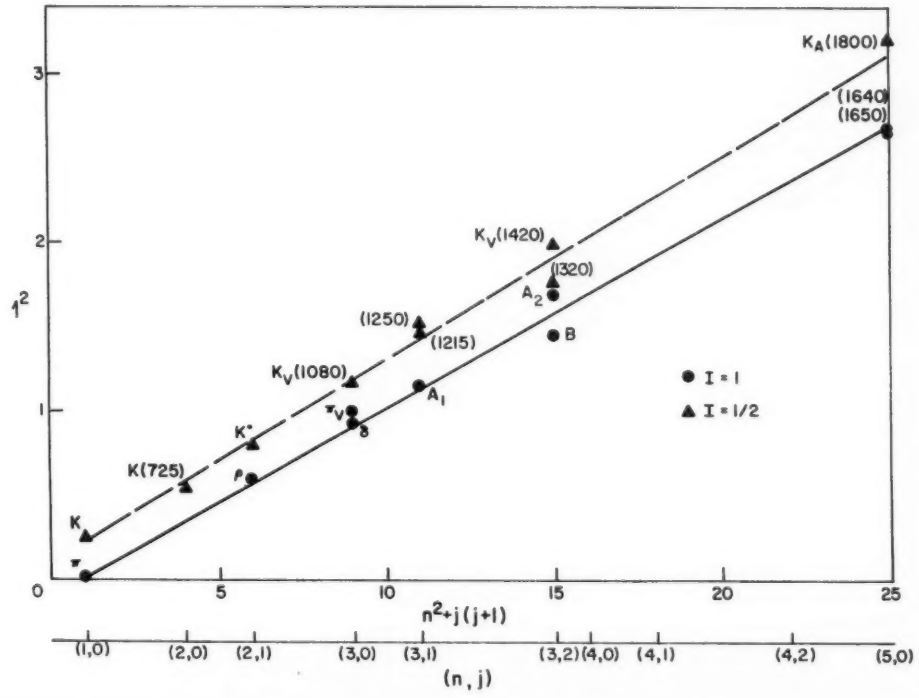


**Figure 3.—Assignment of meson levels in 0(4,2) and mass formula. (Barut, A. O., *Nucl. Phys.*)**

(Figure 4), as well as magnetic moments and partial decay rates of metastable excited states. The essential property of the high-energy, high-momentum transfer scattering of baryons and its relation to the form factors is also correctly and simply explained by the present theory (Figure 5). The lesson we learn is that the interaction of fundamental particles becomes simple if the internal structure is taken into account.

To conclude, although the exact intuitive picture of the "inside" of the proton is still unknown, enough of its properties have been quantitatively explained to suggest that we are dealing again with a structure very much like the H-atom. Qualitatively, meson-nucleon scattering is like electron-H scattering, and pp-scattering is like H-H scattering.

One may call the nucleon and the H-atom the primary structures of the strong and electromagnetic interactions, respectively, whereas nuclei and molecules would be secondary structures, "weakly" bound nucleons and weakly bound atoms, respectively.

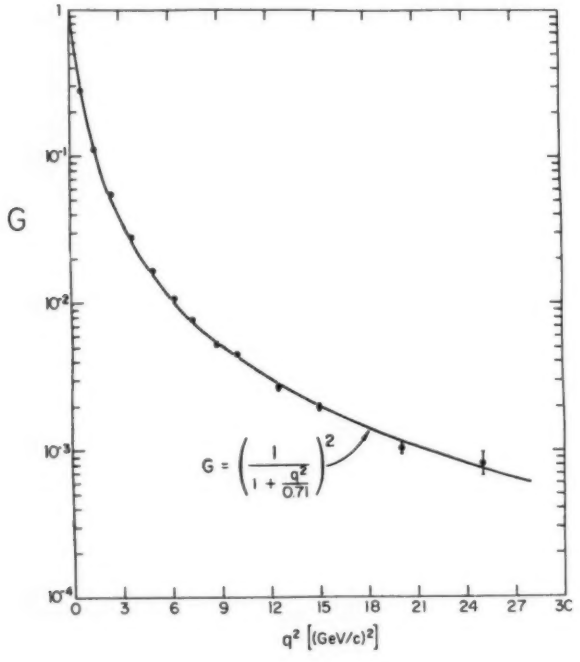


**Figure 4.—Form factor of the proton up to a momentum transfer squared of 25 (GeV/c)$^2$ according to recent measurements at the Stanford Linear Accelerator. (Coward, D. H., *et al*, *Phys. Rev. Lett.*, *20*, 292, 1968.)**

## SUGGESTED FURTHER READING

Early developments of the dynamical group approach have been reviewed in the author's articles in *High Energy Physics and Elementary Particles*, International Atomic Energy Agency, Vienna, 1965; in *Noncompact Groups in Particle Physics*, W. A. Benjamin, N. Y., 1966; and in *Symmetry Principles and Fundamental Particles*, W. H. Freeman Co., San Francisco, 1967. For more recent work see the reviews of Y. Nambu in *Proceedings of the 1967 International Conference on Particles and Fields*, Interscience Publ., 1967. For the calculation of specific hadron properties see A. O. Barut, D. Corrigan and H. Kleinert, *Phys. Rev. Lett.*, *20*, 167, 1968, and references therein.

*Dr. A. O. Barut received his Ph.D. in experimental work from the Swiss Federal Institute of Technology, Zurich. He has been interested in elementary particles since 1958. Before joining the faculty of the University of Colorado in 1962 as Professor of Physics, he was associated with Syracuse University, the University of California at Berkeley, and the International Centre for Theoretical Physics, Trieste. Dr. Barut is the author of Electrodynamics and Classical Theory of Fields and Particles, MacMillan, 1964, The Theory of the Scattering Matrix, MacMillan, 1967, and of numerous research papers. The work he describes here is supported by AFOSR.*

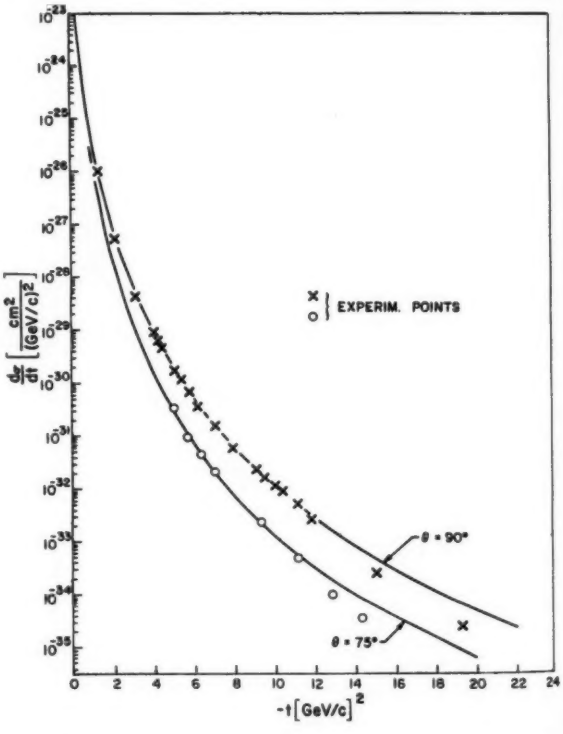


**Figure 5.—Large momentum transfer proton-proton differential cross section at fixed angle compared with the theoretical calculations based on a simple contact interaction. (Barut, A. O. and D. Corrigan, *Phys. Rev.*)**

# veiling of starlight during sunshine in near-space

AERONOMY LABORATORY
AFCRL

Most of us know that the reason we don't see stars in the daytime is that the scattering of sunlight by atmospheric molecules and aerosols veils the weak light of the stars. From this the inference had been drawn that the first astronauts would be able to see sharp points of starlight sharing a black sky with the brilliant disk of the sun. But when the first men in space looked out at the sunlit sky, they saw no stars at all—except, occasionally, a few of the very brightest. Even optical physicists, who are concerned most directly with the attenuation and transmission of light, did not anticipate this starless view of the heavens.

Now that our earlier suppositions have been proved wrong, investigators have come forward with explanations as to why stars are veiled in the near-space region in the presence of sunlight. Three reasons have been given. The first has to do with sky luminance—airglow and the still-present atmospheric particles which scatter sunlight. The second concerns what is called spacecraft corona. Spacecraft corona is essentially a cloud of light-scattering particles that are ejected from the spacecraft and move along with it. The third star-veiling mechanism is the scattering of light from the spacecraft and within its glass windows.

Dr. Sam M. Silverman of AFCRL and J. W. F. Lloyd of Northeastern University have looked into the relative contributions of these three veiling mechanisms and have suggested a fourth contribution which could be the most important of all. Their study has involved the re-examination of data acquired by rockets sent aloft over the past several years to measure airglow.

With respect to the first three postulated veiling mechanisms, Silverman and Lloyd conclude that the first, sky luminance, is much too weak at satellite altitudes to interfere with daylight star sightings. The second factor, spacecraft corona, is also discounted—but with reservations, since not enough is known about the size and density of the particles that accompany the vehicle. Furthermore, the flux of these particles should decrease with flight duration. Scattering by spacecraft and within the spacecraft windows is the most difficult to estimate of the three mechanisms, and no reliable conclusion has been drawn with respect to this source. This is not to say, however, that it is not an important veiling source.

Nevertheless, a fourth mechanism suggested by Silverman and Lloyd may be the major cause of stellar veiling. This is simple glare. Glare consists of light that is in the field of view of the observer but not in his direct line of sight. Glare, in the sense that Silverman and Lloyd consider it, has nothing to do with the physiology of the eye and its dark-adaption mechanism. What is suggested here is the situation one finds when one stands in a darkened room looking out at the night sky. If lights are turned on in the room, stars previously visible are obscured. Sunlight and reflected earthlight are the most prominent glare sources. Additional sources are found within the spacecraft itself in the many pilot and control lights.

The total amount of veiling illumination from glare is difficult to calculate, representing as it does a consideration of the complex geometries of many light sources and surfaces within the spacecraft available for multiple reflections.

Had the problem been considered initially in terms familiar to the radio physicist—namely, in terms of signal-to-noise ratio in which the intensity of the illumination of the star (the signal) is calculated against the intensity of all other sources of background illumination (the noise), it is unlikely that the erroneous assumption of daylight star visibility would have been made in the first place.

# AFCRL Satellite Placed in Orbit

IONOSPHERIC PHYSICS, AERONOMY, and AEROSPACE INSTRUMENTATION LABORATORIES, AFCRL

ATCOS II (for ATmospheric COmposition Satellite), a satellite designed, constructed, and instrumented by AFCRL, was successfully placed into a circular polar orbit on December 4, 1967. This satellite is one in a series of low-cost Orbiting Vehicle (OV) satellites, and bears the numerical designation OV3-6. Launched with a scout rocket and having a payload weight of 219 pounds, ATCOS II is designed for a 256-day lifetime. The satellite, launched from Vandenberg AFB, has an orbital height of 435 km and a 90-degree inclination.

Experiments aboard the satellite were designed by Rocco S. Narcisi, James C. Ulwick and Joseph P. McIsaac, all of AFCRL. Carrying a research payload consisting of two mass spectrometers, three ion-density gauges, and an impedance probe, the satellite is performing two basic experiments. The mass spectrometers and ion-density gauges form one basic experiment, under the direction of Narcisi and McIsaac, measuring such properties as atmospheric composition, density, pressure, and temperature. The impedance probe, in the second experiment designed by Ulwick, is measuring temperature irregularities and electron density.

Charles H. Reynolds of AFCRL is the satellite Program Manager.

# COMPUTER LINGUISTICS

**DATA SCIENCES LABORATORY, AFCRL**

When the March Hare insisted that Alice should say what she meant, and Alice hastily replied, "I do. At least—at least I mean what I say—that's the same thing, you know," the linguistic logic of the interchange was all with the March Hare. Like the March Hare, computers demand precision when we try to talk to them. All we English-speaking Alices, if we want to make our meaning clear to computers, have no choice but to re-examine the underlying structure and logic of our language.

This takes us into linguistics. Through a study of the deep underlying constructions of language, linguists believe that it may be possible to discern something of the basic behavioral patterns of a person or of a people, and perhaps to define the very limits of the human ability to communicate. Modern linguistics is a far journey from the simple rules of grammar to which we were first exposed in the seventh or eighth grade. We may or may not retain much of what we learn, but it's not particularly important that we

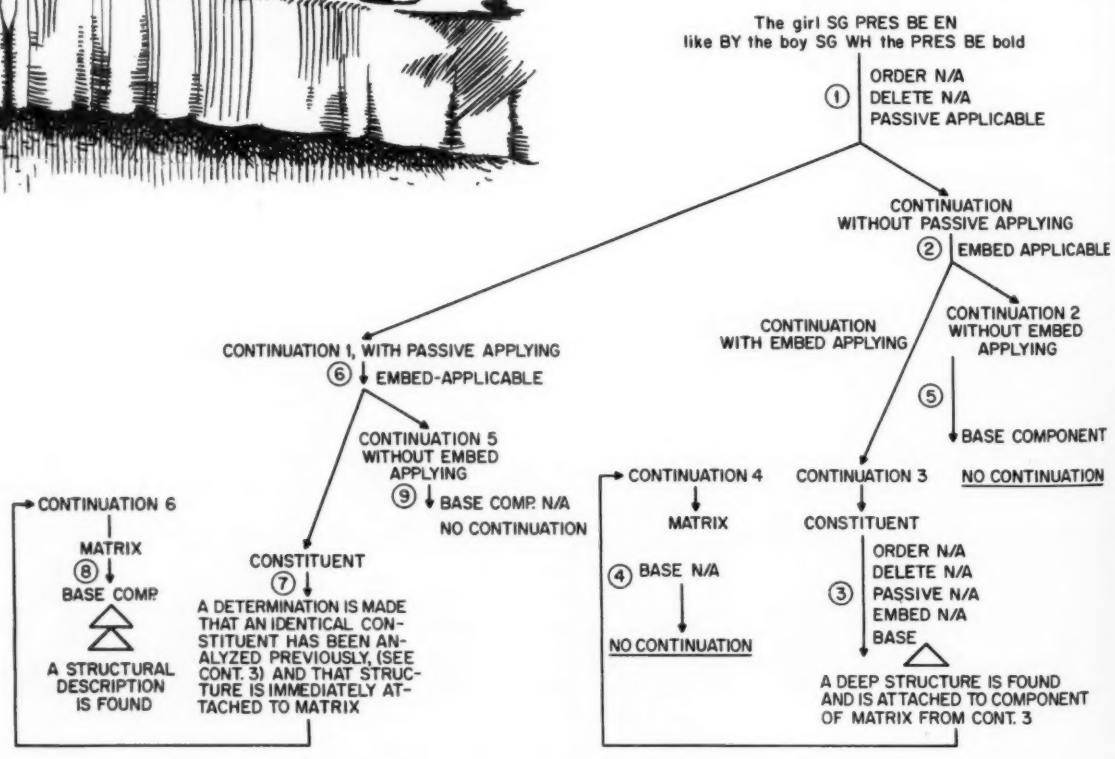


**Figure 1.—From the standpoint of the computer attempting to put a string of English words together in meaningful order, the syntax of the simple sentence, "The girl likes the boy that is bold," is highly complex. This chart schematically represents the paths taken by the analysis procedure. Unless you are somewhat familiar with computer linguistics, don't try to figure out the steps or the reasons for them. This schematic, nevertheless, will serve to give you an impression of the analytic procedure.**

do because, for the rest of our lives, we speak and listen and read and write. From this, we come to know without conscious consideration whether or not a particular string of words is grammatically correct and has meaning.

But when we set out to speak to computers in a natural language (in English, for example, as opposed to artificial languages such as COBOL, LISP or FORTRAN), we find that our simple grammatical rules are much too lax, and that they abound with logical traps. The computer cannot take our string of words and give them the proper relationship to derive the meaning we intended.

Programming a computer in a natural language is a field of study that is just emerging as a distinct subcategory of both linguistics and computer software research. Although the artificial languages of COBOL, LISP and so on are themselves an exercise in linguistics, AFCRL took the initiative early in studying the linguistic requirements for programming a computer directly in English. Researchers have taken several approaches toward the formulation of notations, or algorithms, that set forth rules of English grammar for computers. Among the most promising of these are algorithms developed at AFCRL by Dr. Stanley Petrick (now at IBM). The problems of programming a computer in a natural language, and the methods of designing relationships between words and phrases in a sentence are summarized in the AFCRL report, "Syntactic Analysis" (AFCRL-67-0305) by S. J. Keyser (of Brandeis University) and Stanley Petrick.

Programming in a natural language is a multilayered problem. One problem involves simple ambiguity of the type found, for example, in the sentence, "The boy looked over the wall." Do we mean that he peered over it, or that he examined it? Such simple ambiguities are easily resolved.

The real problem in formulating a computer grammar is that a sentence can be constructed in many different ways to express the same thought. For no good reason at all, we sometimes use the active voice and sometimes the passive voice. In the following example the meaning is the same, although the arrangement of the words is quite different: "The book amazed John," and "John was amazed by the book." The key to the Petrick notation system is that it readily permits the computer to transform a particular sentence from active to passive or from passive to active without a loss of the intended logical relationships of the words.

The Keyser-Petrick report discusses the special notations required for a variety of sentence types. Among these are sentences with many embedded components such as "The girl likes the boy that works in the store that is owned by the man." Humans quickly sort out, categorize and assign relationships among such strings of words with the habitual ease of instinct. Computers, with a very limited capability to learn or to reinforce their performance through experience, must view each new sentence presented as a new experience.

Given a natural English sentence, one properly formed according to the special computer-oriented grammatical rules, how well does the computer perform? At the present time, the performance is at best inadequate. One would wish, ideally, a more direct correlation with human recognition patterns. In fact, a comparison of human and computer performance gives us a measure of how well the computer is doing. An example may help explain what we mean here. Humans more quickly perceive the meaning of a noun phrase such as "the old man" than "the man that is old." (Both have the same meaning.) But for the computer, the reverse is true. The computer, given the present computer-oriented grammar, has a much harder time coping with the rules for recognizing the phrase, "the old man."

The programming rules under study at AFCRL and elsewhere are essentially a first-generation approximation. Keyser and Petrick conclude their report with the comment that, although the present routines are not satisfactory for modeling human recognition, the work is providing a rich background of experience for a fresh assault.

*Dr. Stanley R. Petrick, until recently a research mathematician with AFCRL's Data Sciences Laboratory, and now with IBM, has been active in applying linguistic theory to the area of man-machine communication. He was particularly concerned with developing methods for finding all of the structural descriptions of a sentence assigned by a given transformational grammar, and for evolving methods to map those structural descriptions into appropriate natural language or computer-language translations. Dr. Petrick has a B.S. in Mathematics from Iowa State University (1953), an M.S. from M.I.T. (1955), and a Ph.D. in Linguistics from M.I.T. (1965). He was formerly an officer with the U.S. Air Force prior to joining the Data Sciences Laboratory in 1955. He is a member of Pi Mu Epsilon, Phi Kappa Phi, Sigma Xi, the American Mathematical Association, the Linguistic Society of America, and other professional societies.*

# The Use of Thin-Layer Electrochemical Cells

**LT COL EDWARD T. WALFORD**
**Directorate of Chemical Sciences**
**AFOSR**

The improved batteries and fuel cells of today are based primarily on improved technology rather than on new science. These improvements have resulted generally from advances in the composition and form of the materials used or from new machinery or processing methods. While these innovations have sometimes led to a better understanding of the basic phenomena involved, the electrochemical process still remains shrouded in mystery. A recent DoD study (1) on this subject concludes that "the lack of fundamental understanding of the statics and dynamics of electrochemical systems is a substantial deterrent to progress in electrochemical energy conversion."

The chemical nature of the electrochemical process needs to be investigated in order to arrive at a complete description of the energy-conversion process in a cell. In particular, kinetic and mechanistic studies must be made of the chemical reactions which occur prior to, or following, electron transfer. The last decade of electrochemistry has seen the development of a variety of techniques readily adaptable to studies of this nature. One of these methods, thin-layer electrochemistry, has been adapted and improved by Drs. C. N. Reilly and R. W. Murray, co-investigators on an AFOSR grant at the University of North Carolina. (2)

Reilly and Murray have developed a mini-cell which is technically known as a micrometer-type, twin-electrode, thin-layer cell (Figure 1). Their design provides fast and direct measurements because of its relatively unique characteristics of rapid mass transfer, large ratio of electrode area to cell volume, and generation of steady-state rather than transient currents under certain conditions.

In the usual method of operation, the cell is loaded with an appropriate electrolyte and the cell thickness is set.

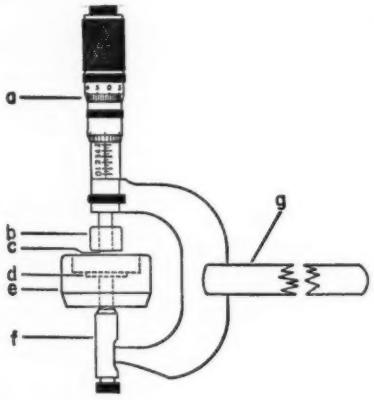


**Figure 1.—Thin-Layer Micrometer Electrode: (a) outer thimble for direct reading to one ten-thousandth of an inch; (b) press-fitted Teflon collar; (c) platinum face of the micrometer spindle; (d) flat glass disk pressed into the Teflon cup against the face of the detachable anvil; (e) cup machined from Teflon; (f) Starrett No. 212 detachable anvil; (g) stainless steel rod for mounting cell assembly.**

(An important advantage of this technique is that the thickness of the solution is accurately known and can be varied easily from 1 cm to 1 x $10^{-3}$ cm.) The electrodes are placed at a potential which does not disturb the system under study. A step potential is then applied to the system and the current response is observed.

The current response may be zero, steady-state, or changing with time. Under these 3 types of responses, there exist at least 14 types of chemical systems which can be studied. (3) (Thin-layer cells have been used to obtain equilibrium constants, rate constants, diffusion coefficients, and adsorption parameters.)

The experimental arrangement of the working electrodes in the thin-layer cell also allows the simple substitution of different electrodes. The investigators plan to study various electrode materials, such as graphite, conducting glass, and silicon carbide. The method should also be ideal for detecting surface oxidation or reduction of the electrode materials.

Dr. Murray has reported recently on another modification of the thin-layer cell. (4) There has been a need for *in situ* spectral observation of the chemical products formed during the electrochemical process. Dr. Murray has developed a very simple optically transparent electrode which allows the transmission of spectral observations during and after the electrochemical reaction.

The cell (Figure 2) is of fixed thickness and can be made in the range of 20-100 microns. A gold minigrid (1000 wires/inch) is used as the optically transparent electrode. This cell should be valuable for routine investigations of new systems where simultaneous electrochemical and spectral

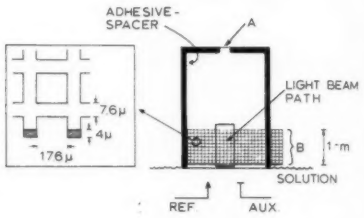


**Figure 2.—Thin-Layer Cell with Optically Transparent Electrode.**

measurements are necessary to identify the electrode reactions.

The research described above is a good example of the basic advances being made by AFOSR-sponsored investigators. Electrochemistry is a research area which is extremely relevant to the needs of the Air Force. AFOSR's Directorate of Chemical Sciences recognizes this and attempts to maintain a significant program of support.

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# GRAVITATION-INDUCED ELECTRIC FIELD NEAR A METAL

CAPT DONALD R. LEHMAN, Directorate of Physical Sciences, AFOSR

Recent experimental attempts by Stanford physicists F. C. Witteborn and W. M. Fairbank to determine whether positrons possess normal gravitational properties have required an understanding of gravitationally induced fields near a metal. The experiment involves the observation of freely falling electrons and positrons, with the objective of showing directly whether antiparticles (positrons) fall down or fall up in the earth's gravitational field. This experiment must be performed in a long cylindrical tube of metal so that the particles may be shielded from external electric fields. But then the question arises as to whether the mere presence of the metallic shield might produce an electric field, due to the influence of the earth's gravitational field on the electrons and nuclei that make up the metal. If this were the case, it might constitute an important correction that would have to be applied before the results of the experiment could be interpreted.

A quantum-mechanical formalism has been developed by L. I. Schiff and M. V. Barnhill (1) of Stanford University, whose research is supported by the Nuclear Physics Division of AFOSR, to calculate the electric field produced in the vicinity of a metallic object by the influence of the earth's gravitation. Surprisingly enough, an exact solution to the many-body equation can be obtained. The resulting expression for the electric field, which includes consideration of the supports and compressibility of the metal, can be reduced to the solution of a problem in classical electrostatics, valid for a superconductor as well. The conclusion is that a shielded electron would *not* be accelerated at all, since the gravitational force is exactly cancelled by the gravitation-induced electric field. A positron that is acted on by gravity in the normal way would be expected to fall with an acceleration of 2g, where g is the acceleration due to gravity on the surface of the earth and is approximately equal to 980 $cm/sec^2$.

Experimental confirmation of the first of these two conclusions has recently been completed. By means of a free-fall technique, Witteborn and Fairbank (2) have measured the net vertical component of force on electrons in a vacuum enclosed by a copper tube. Their results show that this force is less than 0.09 mg, where m is the inertial mass of the electron. The predicted effects of gravity on electrons in a metal are therefore substantiated. However, due to the difficulty of producing extremely low-energy positrons and thus performing a similar experiment with antimatter, it may be some time before the second conclusion can be experimentally tested.

The knowledge that there exists a gravitation-induced electric field near a metal may prove to be very useful in numerous areas of physics. For example, as pointed out by Schiff and Barnhill, "It is natural to think of enhancing the gravitation-induced electric field by substituting for gravitational force the much larger centrifugal force that can be obtained by rapid rotation."

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# *a facility for blunt body re-entry flow simulation*

1ST LT ERIC G. FRIBERG
Fluid Dynamics Facilities Research Laboratory, ARL

The Fluid Dynamics Facilities Research Laboratory, ARL, is continually trying to advance the state-of-the-art in facilities design. The problem of simulation of re-entry flow fields is an area in which limited data are available. A novel concept for simulating re-entry flow fields over blunt-nosed bodies has been examined by Mak and Zakkay (1) at New York University, under a contract with ARL.

In wind-tunnel testing, since complete duplication of the flight corridor cannot be achieved for re-entry bodies, the aerodynamicist must resort to simulation, i.e., the duplication of those parameters most intimately associated with the phenomenon being studied. An additional problem engendered by hypersonic high-altitude flight is the requirement that the chemical kinetics of the flow field be simulated.(2) Criteria for simulation of the flow over re-entry bodies using any gaseous test medium have been found to be the dynamic pressure and the density ratio across the normal shock. Figure 1 shows the derived variation of the coefficient of pressure at the stagnation point as a function of the density ratio.

To simulate the chemical kinetic criteria of the flow field, test gases other than air, primarily nitrogen and argon, have been employed. Recently, however, combustion gas mixtures have been investigated (3) to achieve the proper gas energy level for flight-velocity duplication. One of the important differences between air and these other test gases is in the ratio of specific heats; but it can be shown that this ratio chiefly affects the surface Mach number distribution,

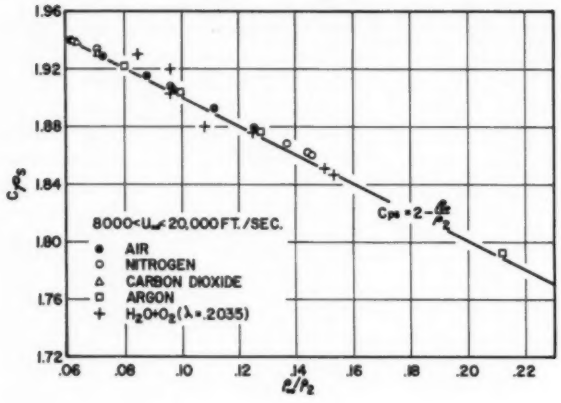


**Figure 1.—Coefficient of pressure at the stagnation point as a function of density ratio across a normal shock wave in equilibrium gas mixtures.**

while other important parameters may be simulated reasonably well.

The use of a steam-oxygen mixture of equivalence ratio 0.2035 has been proposed by Mak and Zakkay (1) to simulate the important parameters in blunt-body re-entry flow fields. By using this mixture, it is possible to obtain simulation at the stagnation point with relatively low stagnation temperatures. $H_2O$–$O_2$ mixtures eliminate the combustion-product contamination problem. Also, in view of the well-understood $H_2O$–$O_2$ reaction, the upper temperature limit may be extended sufficiently to suppress any condensation problems in the free stream, despite the onset of molecular dissociation and nonequilibrium flow conditions.

A buffered shock facility using the steam-oxygen mixture as the test medium to simulate the flow over blunt-nosed reentry bodies has been proposed in Reference 1. This facility would be capable of producing maximum testing times of about 6 milliseconds for a normal-size shock tunnel. Flow Mach numbers up to about Mach 10 could be obtained at static temperatures of 300°K using a reflected shock technique. The high pressures required to drive such a buffered shock tube at the requisite stagnation temperatures are available from the New York University high-Reynolds-number hypersonic test facility, the design of which was also sponsored by the Aerospace Research Laboratories. This method, if proven successful, could offer a new versatility in aerospace ground-test facilities.

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*1st Lt Eric G. Friberg is assigned to the Fluid Dynamics Facilities Research Laboratory, ARL. As a project engineer on the Mach-14 hypersonic wind tunnel, his primary responsibilities are to assure the operation of, and to aid testing in, this facility. He directs several projects in facilities research.*

*Lt Friberg was graduated from Harvard University in 1964 with an A.B. in Engineering and Applied Physics. He received his S.M. in Aeronautics and Astronautics from the Massachusetts Institute of Technology in 1965. He is now a doctoral candidate in Aeronautics and Astronautics at the Ohio State University.*

*Lt Friberg was commissioned in the Air Force through the AFROTC program in 1964, and took an educational delay from active duty to obtain his master's degree. He has been assigned to ARL since September 1965.*

**Lt. Friberg at the control panel of the ARL component test facility. This test facility is used to improve operational reliability and performs as well to provide advanced design criteria for wind-tunnel components.**

# INJECTION–LOCKED MAGNETRON WITH LOW–INPUT POWER

MICROWAVE PHYSICS LABORATORY, AFCRL

AFCRL has demonstrated that a magnetron can be locked in frequency and phase–with pulse-to-pulse coherence–to an external oscillator having an injection power 40 db below the magnetron's output power. This input-output power ratio is 20 db better than ratios previously attained in injection-locked magnetron systems.

This development could lead to a reappraisal of the magnetron as a radar power source. The magnetron, once the key component in radar systems, has seen decreasing use since the introduction of the klystron in the early 1950's. Injection-locked magnetrons of the type demonstrated at AFCRL could, however, offer several advantages over the klystron–light weight. power efficiency, and possibly improved moving-target-indication (MTI) performance because of high frequency and phase stability.

Injection-locked pulsed magnetrons, as such, are hardly a new concept. During World War II, scientists at MIT's Radiation Laboratory toyed with the concept of injection-locked magnetrons. A design is described in the well-known and still-useful Radiation Laboratory Series. The technique is based on the familiar principle that, when the power from one oscillator is allowed to enter the interaction circuit of another higher-powered oscillator (such as a magnetron), the high-power oscillator will lock or synchronize to the lower-powered one–assuming, of course, that the frequencies of both are fairly close.

The AFCRL system was built with off-the-shelf components, the most important one being a positive anode beacon-type magnetron developed by Microwave Associates. Another important reason for the high performance is the high spectral purity of the low-power-input oscillator. These elements, together with other improved components such as diode switches and attenuators, resulted in the high performance of the system.

In the AFCRL system, injection power is taken from an X-band stable local oscillator (STALO) incorporating a high Q-factor reference cavity. The magnetron can lock in phase with as little as 25 milliwatts of input power from the STALO. Peak output power from the magnetron is about 250 watts, which corresponds to a gain, or injection ratio, of about 40 db. The system operates at 9.28 GHz and has a pulse-repetition frequency of 1,000 pulses per second. The X-band STALO providing the injection power has a stability measured in a few parts in a million per hour.

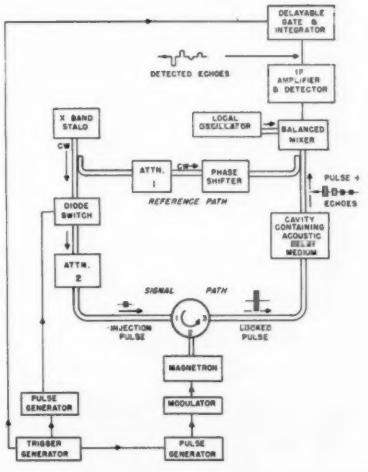
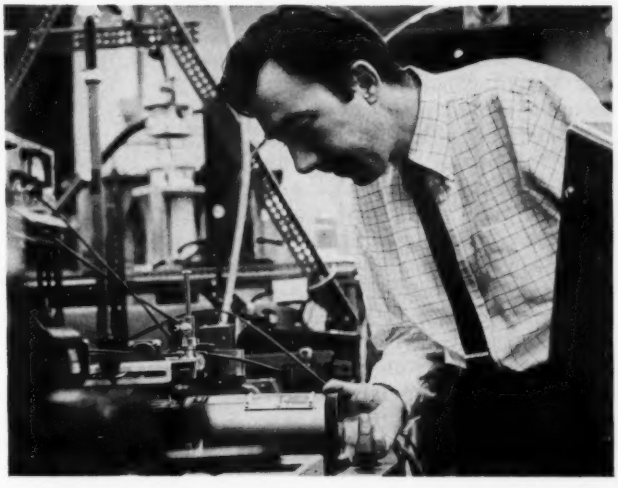



**Figure 1.–Block diagram of essentials of coherent X-band system employing injection-locked magnetron.**

The injection-locking magnetron system resulted from microwave acoustic research at AFCRL conducted by Marden H. Seavey, Jr. Seavey designed the system as research instrumentation for his acoustic studies, the original objective being to achieve a high-power acoustic interferometer capable of measuring small changes in acoustic velocity.

Although the present system operates at relatively low power, it can be used in a high-power system as an element in a cascade network. (In this network, the stable magnetron output pulse would provide a locking source for higher-powered magnetrons.) Seavey and his group are planning a similar system operating at Ka band (36 GHz) with a 500-watt output.

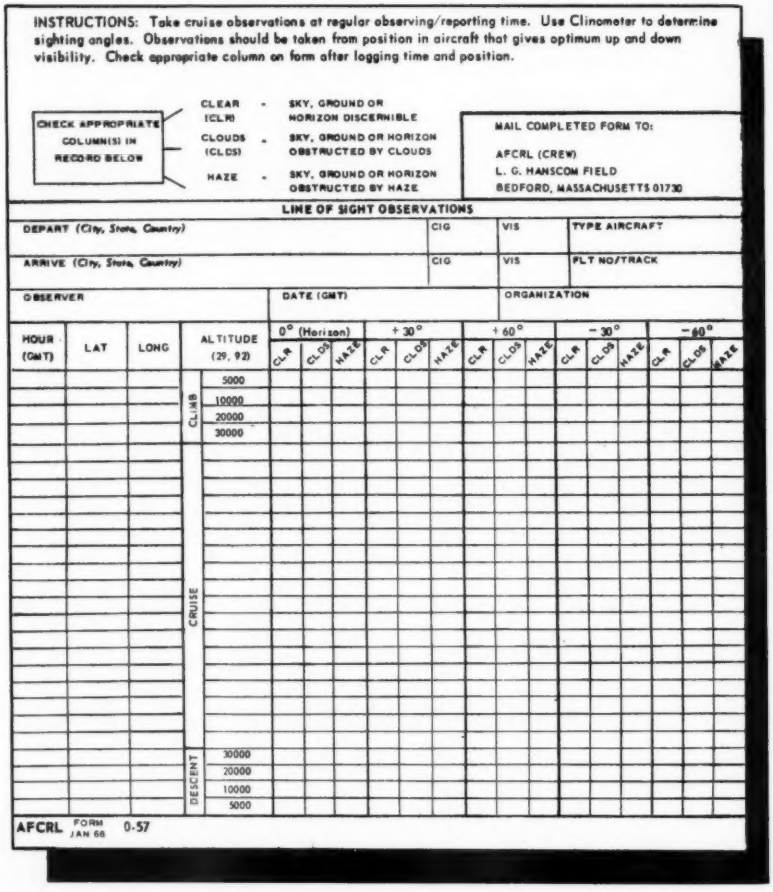
*Mr. Marden H. Seavey, Jr., a solid-state research physicist, is studying microwave ultrasonics in ferromagnetic and antiferromagnetic materials during his current assignment with the Microwave Acoustics Branch of AFCRL's Microwave Physics Laboratory. Mr. Seavey received his A.B. in Physics from Harvard University (1952), his M.S. in physics from Northeastern University (1956), and attended the graduate schools at both Brandeis University and Harvard University for further study in physics. Before his present assignment at AFCRL, he had been a physicist at M.I.T.'s Lincoln Laboratory. Mr. Seavey is a member of the American Physical Society.*



**Mr. Seavey is shown examining the new magnetron equipment.**

**AEROSPACE INSTRUMENTATION LABORATORY AFCRL**

# clear lines of sight from aircraft



INSTRUCTIONS: Take cruise observations at regular observing/reporting time. Use Clinometer to determine sighting angles. Observations should be taken from position in aircraft that gives optimum up and down visibility. Check appropriate column on form after logging time and position.

CHECK APPROPRIATE COLUMN(S) IN RECORD BELOW

CLEAR (CLR) - SKY, GROUND OR HORIZON DISCERNIBLE

CLOUDS (CLDS) - SKY, GROUND OR HORIZON OBSTRUCTED BY CLOUDS

HAZE - SKY, GROUND OR HORIZON OBSTRUCTED BY HAZE

MAIL COMPLETED FORM TO:
AFCRL (CREW)
L. G. HANSCOM FIELD
BEDFORD, MASSACHUSETTS 01730

LINE OF SIGHT OBSERVATIONS

DEPART (City, State, Country) | CIG | VIS | TYPE AIRCRAFT

ARRIVE (City, State, Country) | CIG | VIS | FLT NO/TRACK

OBSERVER | DATE (GMT) | ORGANIZATION

| HOUR (GMT) | LAT | LONG | | ALTITUDE (29, 92) | 0° (Horizon) CLR | CLDS | HAZE | + 30° CLR | CLDS | HAZE | + 60° CLR | CLDS | HAZE | - 30° CLR | CLDS | HAZE | - 60° CLR | CLDS | HAZE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CLIMB | 5000 | | | | | | | | | | | | | | | |
| | | | | 10000 | | | | | | | | | | | | | | | |
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AFCRL FORM JAN 68 0-57

**AFCRL Form for collecting clear lines-of-sight data. (Figs. 1a and 1b show front and back of form.)** **Figure 1a.**

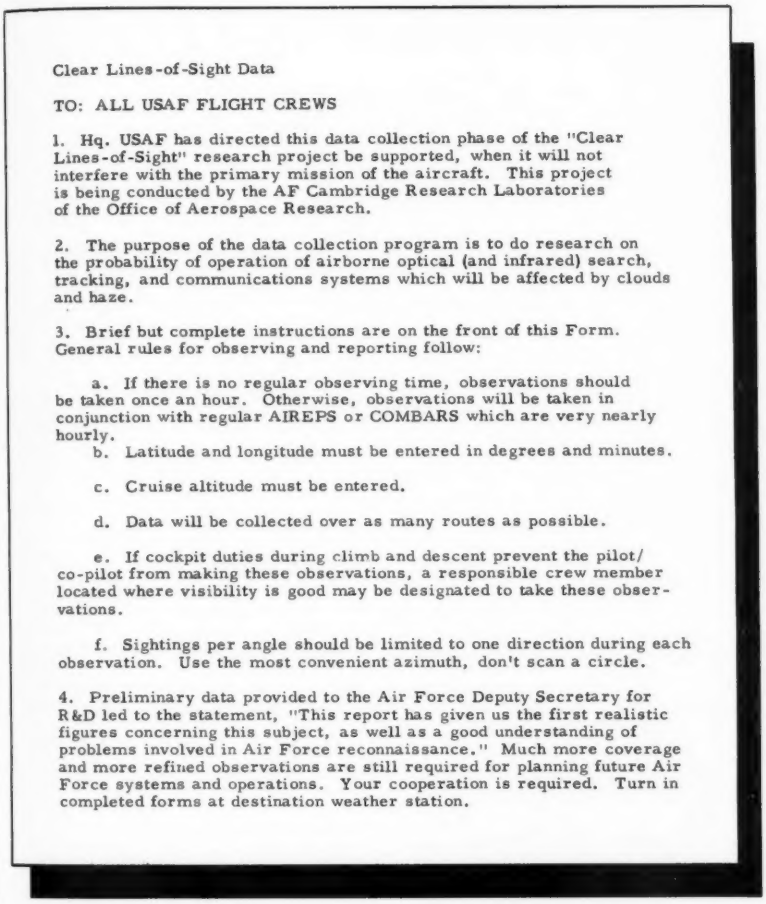
What appears to be a clear day to the ground observer looking up may not be a clear day to the observer in an aircraft looking down. This is the basic conclusion reached in an 18-month study by AFCRL on clear lines of sight from aircraft. The study involved more than 72,000 observations covering much of the Northern Hemisphere.

Making observations for AFCRL were pilots and aircrew members of the Strategic Air Command, Military Airlift Command, weather reconnaissance squadrons, the U.S. Navy, and Pan American World Airways. The last of these, Pan American, participated on a no-cost basis. Special AFCRL forms were supplied to each of these organizations, and monthly submissions of these completed forms were made to AFCRL. (See Figures 1a and 1b)

Motivating AFCRL in this study was the need for precise statistical data on the impact of cloudiness on the design of optical and infrared airborne detection and tracking systems. The data also apply to similar ground-based systems.

Pilots and aircrew members were asked to make observations at 5 different angles—minus 90 degrees (directly below the aircraft), minus 30 degrees, 0 degrees (the horizon), plus 30 degrees, and plus 90 degrees (directly overhead). Observations were made at altitudes ranging from 1,000 feet to above 45,000 feet. The first phase of the program has been completed and a report, "Clear Lines of Sight From Aircraft" (AFCRL-67-0435) by Eugene A. Bertoni, has been published. The report contains more than 160 plates with isopleths overlaying the North American continent and indicating the probability of observing the ground, horizon, or sky at each of the 5 angles as a function of altitude, season, and geographical location. (See Figure 2)

The report contains many surprises. One of these is the great difference between an estimated probability of clear lines of sight derived from a modeling technique and actual frequencies of clear lines of sight obtained from the observational data. For example, data from 300 observations over the Washington, D.C. area were compared with the lines of sight predicted by the model and based on climatological records from the area. The estimates indicated a 75-percent likelihood of seeing the ground at a



Clear Lines-of-Sight Data

TO: ALL USAF FLIGHT CREWS

1. Hq. USAF has directed this data collection phase of the "Clear Lines-of-Sight" research project be supported, when it will not interfere with the primary mission of the aircraft. This project is being conducted by the AF Cambridge Research Laboratories of the Office of Aerospace Research.

2. The purpose of the data collection program is to do research on the probability of operation of airborne optical (and infrared) search, tracking, and communications systems which will be affected by clouds and haze.

3. Brief but complete instructions are on the front of this Form. General rules for observing and reporting follow:

a. If there is no regular observing time, observations should be taken once an hour. Otherwise, observations will be taken in conjunction with regular AIREPS or COMBARS which are very nearly hourly.

b. Latitude and longitude must be entered in degrees and minutes.

c. Cruise altitude must be entered.

d. Data will be collected over as many routes as possible.

e. If cockpit duties during climb and descent prevent the pilot/co-pilot from making these observations, a responsible crew member located where visibility is good may be designated to take these observations.

f. Sightings per angle should be limited to one direction during each observation. Use the most convenient azimuth, don't scan a circle.

4. Preliminary data provided to the Air Force Deputy Secretary for R&D led to the statement, "This report has given us the first realistic figures concerning this subject, as well as a good understanding of problems involved in Air Force reconnaissance." Much more coverage and more refined observations are still required for planning future Air Force systems and operations. Your cooperation is required. Turn in completed forms at destination weather station.

**Figure 1b.**

minus-30-degree angle from 30,000 feet during the winter months. The actual data accumulated by AFCRL indicate the likelihood to be only about 20 percent. Discrepancies equally as great occurred in the Seattle area. It appears that what is a clear line of sight looking upward from the ground is not necessarily a clear line of sight to a member of an aircrew looking down.

Some of these differences—but not all—can be accounted for by "thin" clouds. Thin clouds should be discussed in the context of sunshine recorders in order to show how erroneous assumptions can arise. In major cities all over the country, sunshine recorders plot the times of the day that the sun is visible in the sky. The recorders provide daily records extending back several decades. It was assumed that, if the sun could be seen at a certain angle, then an aircraft looking down from the same angle would also see the ground. Although the sun can be seen through thin clouds, the ground from above often cannot. Similarly, smoke, haze, and ground fog may not obscure the sun, but could very well obscure the ground from above.

The AFCRL observation program provided a wealth of detail. Here is a sampling:

1) Highest probabilities in winter of a clear line of sight looking at the surface from 25,000 to 35,000 feet are over land areas, with probability decreasing as ocean areas are approached.

2) In general, there is a 20-to-30 percent chance of not seeing blue sky from altitudes of 25,000 to 35,000 feet in winter.

3) A distinct horizon is seen more than 50 percent of the time along 40-degrees latitude in winter from 25,000 to 35,000 feet.

4) During fall in the San Francisco sector, the probability of seeing the horizon increases from 51 percent at 5,000 feet to 70 percent at 40,000 feet, a complete reversal of the altitude trend during other seasons.

The AFCRL study took place in 1965 and 1966 and therefore cannot reflect possible long-term climatological trends. A follow-on effort is now planned. For this effort, one new feature will be added. Pilots and observers will be provided with a small, inexpensive, but specially designed

instrument for making precise measurements of the "look" angle.

The British Ministry of Defence has expressed an interest in joining AFCRL in the follow-on program, and has requested several hundred of the AFCRL-developed look-angle devices (designated clinometers) for distribution to the various RAF commands.

*Mr. Eugene A. Bertoni, a research meteorologist in the Design Climatology Branch of AFCRL's Aerospace Instrumentation Laboratory, is presently working on climatological problems relating to clear lines of sight from aircraft at various altitudes. Mr. Bertoni studied mathematics at Boston University. After military service as an aerographer with the Navy during the Korean war, he became a meteorological aide in 1952 in the Medium-Scale Section of the Atmospheric Analysis Laboratory, AFCRC (predecessor of AFCRL). In this assignment he assisted the project scientist in synoptic and mathematical analyses pertaining to numerical weather prediction. In 1956 he became a meteorologist in the Medium-Scale Section, and in 1958 joined the Technique Application and Development Branch of the Meteorological Development Laboratory where he worked on phases of meteorological computational problems relating to the research of the Forecasting Technique Development Project. Mr. Bertoni is a member of the American Meteorological Society.*

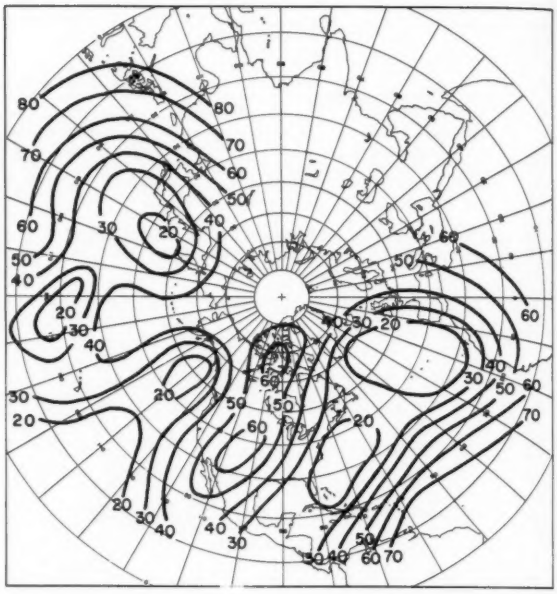


**Figure 2.—If you are flying at an altitude between 25,000 and 35,000 feet, what is the probability of seeing the ground directly below in winter from any location over the North American continent? This chart gives the probability. It is one of some 160 such charts contained in the AFCRL publication, "Clear Lines of Sight from Aircraft."**

**Mr. Bertoni is examining the AFCRL-developed clinometer for measuring "look" angle.**

# PREDICTING THE ONSET AND RETREAT OF MONSOONS

## AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

The monsoon season in the Mekong Delta region of South Vietnam started more or less on schedule in May 1967. The date of onset was predicted with acceptable accuracy by a new prediction method developed by Iver A. Lund of AFCRL. This prediction was based on factors not previously considered to be highly related to monsoons, factors which can be used to predict the retreat of a monsoon as well as its onset. Equations for predicting the retreat of monsoons are described by Lund and Donald D. Grantham, also of AFCRL, in a recent paper, "Estimating the Date of Retreat of the Rainy Season in Southern South Vietnam."

Long-term meteorological records show that the onset of monsoons in southern Vietnam generally occurs during a four-week interval in late April or early May, and that it ends during a similar interval in late November or early December. But there has been no way to predict whether it will begin early or late during any given year.

During the dry season in southern Vietnam, a large area of high pressure covers central Asia, while a low-pressure area extends over the northwestern Pacific Ocean. During the rainy season, these pressure systems are almost completely reversed. In the past, meteorologists have investigated this reversal to find clues that might foreshadow transitions from dry to rainy weather (or from rainy to dry), but with little success.

Two years ago, Lund found that upper-atmosphere wind circulations were more closely linked to the time of transition from dry to rainy weather than were changes near the surface of the earth. He found a consistent precursor to be changes in the height of the 100-millibar surface (about 53,000 feet) over Asia and the western Pacific Ocean. (This pressure surface over Asia may vary from 50,000 feet in the winter to 56,000 feet in the summer.)

The data used by Lund and Grantham to develop prediction equations were derived from rainfall observations taken at three meteorological stations in the Mekong Delta region of Vietnam, and from meteorological balloons (radiosondes), radar, and aircraft observations taken over most of Asia and the western Pacific. The equations were developed using eight years of historical data, and are now being tested on current data.

The goal of this research is to develop methods for skillfully estimating the dates of onset and retreat of rainy seasons several weeks ahead of these events.

**Mr. Iver A. Lund (left) and Mr. Donald D. Grantham are shown studying a weather plotting chart.**

*Mr. Iver A. Lund, a research physicist with the Design Climatology Branch of AFCRL's Aerospace Instrumentation Laboratory, is currently attempting to develop techniques for representing climatology in more meaningful terms. He received a B.A. from the State College at Dickinson, North Dakota, in 1941, and an M.S. in Meteorology from the California Institute of Technology in 1943. He has also studied at the Colorado College of Education, the University of Redlands in California, the University of Southern California, M.I.T., and the University of Chicago. Before coming to AFCRL, Mr. Lund had been a member of the research staff of the California Institute of Technology, and a research meteorologist with the American Institute of Aerological Research. He joined AFCRL in 1951.*

*Mr. Donald D. Grantham, a research meteorologist with the Design Climatology Branch of AFCRL's Aerospace Instrumentation Laboratory, is presently developing mathematical, statistical, and graphical techniques for describing atmospheric parameters and the manner in which these parameters vary in time and space. He received a B.S. in Mathematics and Physical Science from Ball State University in 1959, and in 1960 studied Meteorology at Texas A and M. Mr. Grantham was formerly a weather forecaster with the U.S. Air Force, and chief forecaster with the Air Weather Service Detachments at Fort Sill, Oklahoma, and Thule AFB, Greenland.*

# MAGNETOHYDRODYNAMICS IN MICROSCALE

DWIGHT L. WENNERSTEN
Directorate of Physical Sciences, AFOSR

Research in magnetohydrodynamics has grown enormously in recent years, particularly since the advent of space science. This research is no longer the rather exclusive province of the astrophysicist and cosmologist, but elicits the attention also of the plasma physicist, the radio astronomer, and the planetary meteorologist. (The planetary meteorologist is concerned directly with MHD phenomena, ever since the discovery of the Van Allen belts of the earth and the radio-generating characteristics of the planet Jupiter—types of MHD which are important in planning for both manned and unmanned space flights.)

As a counterpart to real-scale MHD events, considerable attention has been devoted to attempts to reduce MHD phenomena to laboratory dimensions in order to permit a controlled attack on the complex interactions of conductive fluids with magnetic fields. One of these attempts was initiated some 30 years ago by the astrophysicist, Chandrasekhar, at the University of Chicago. He chose liquid mercury as the working substance since it is the only metal which is a fluid at ordinary temperatures and meets the high-conductivity requirement. Also, since mercury is a heavy liquid nearly 14 times as dense as water, the distance factor was scaled down from thousands of miles to inches.

In recent years, solar-planetary interactions through the MHD solar wind have revived interest in this area. One group, under Professor R. H. Donnelly, has reactivated the University of Chicago project using some of Chandrasekhar's equipment—notably, an old cyclotron magnet—but with improved instrumentation and computer-assisted data reduction. This group found that modest improvements in the theory of MHD action in plate-type thrust bearings, to include inertial effects of the working fluid, brought theory and experiment into close agreement. Basically, the effect investigated concerned the prediction that a conductive lubricating film (mercury) entering near the axle of a thrust bearing would have to travel a longer, spiral path in progressing to the lubricant film. Thus, it would support a greater load while travelling the longer distance. Figure 1 (from reference 1) shows the pressure

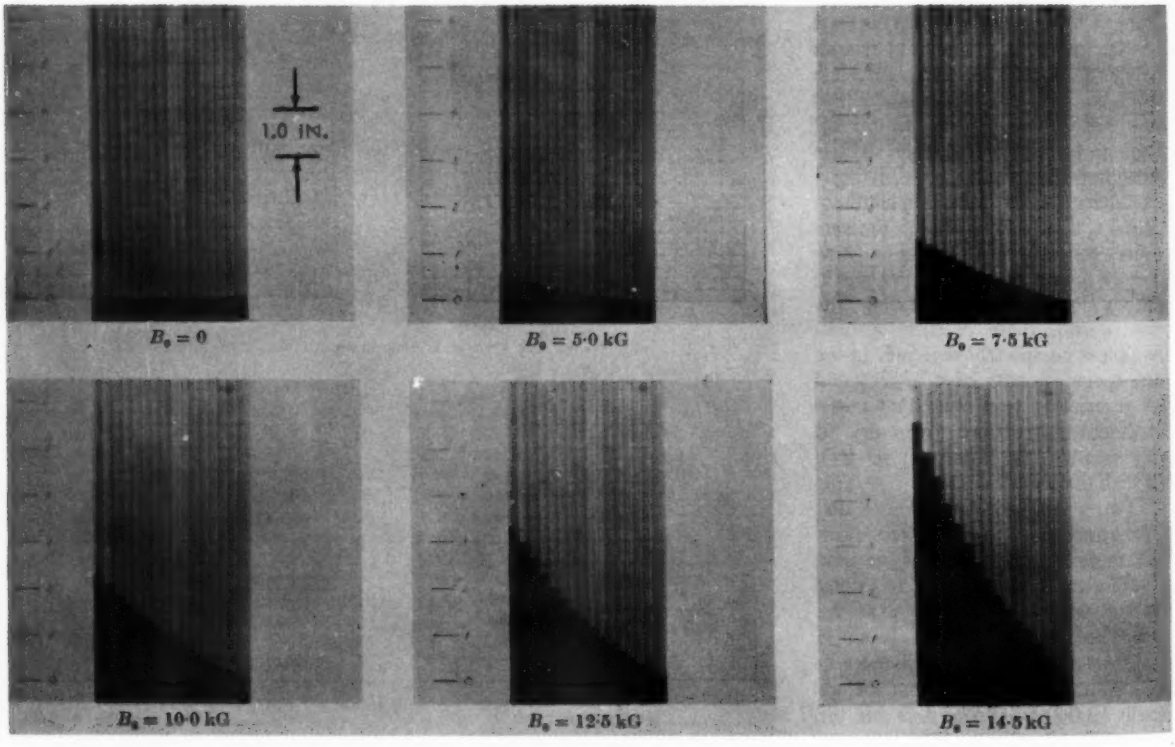



**Figure 1.—Pressure profiles at various magnetic fields for Q = 1·65 in.$^3$/sec and h = 0·0278 in.**

increases as the magnetic field is increased.

These data show that MHD can be scaled into laboratory dimensions with present theories. They also show that the load-carrying capacity of a bearing can be increased. This increase, however, may be only of moderate importance since increased pumping pressure may be more useful in real situations.

Recent work supported by AFOSR is exemplified by Figure 2 (taken from reference 2). This figure shows an air bearing combined with an MHD thrust bearing. Figure 3 shows the measured bearing torques when this assembly was operated in the 32.5-inch cyclotron at the University of Chicago, with a new addition, i.e., the passing of a DC current from the outer electrodes (of Figure 2) to the inner electrodes. This figure shows that a current magnitude can be found which reduces the total bearing torque to zero for any magnetic field or, alternatively, that bearing torques can be made either positive or negative, using reasonable currents in the magnetohydrodynamic film. The significance of these findings is yet to be determined, but they provide an interesting new possibility for bearing-performance control.

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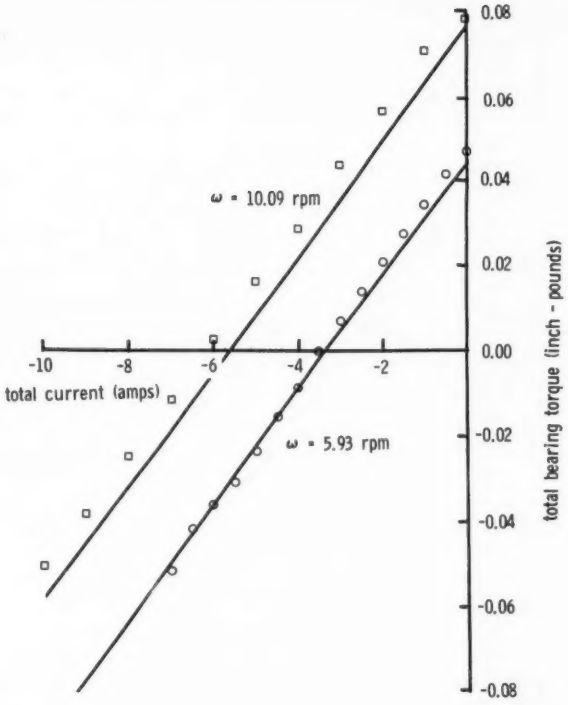


**Figure 3.—Total bearing torque versus total current at various speeds for a magnetic-field strength of 10.0 kilogauss.**

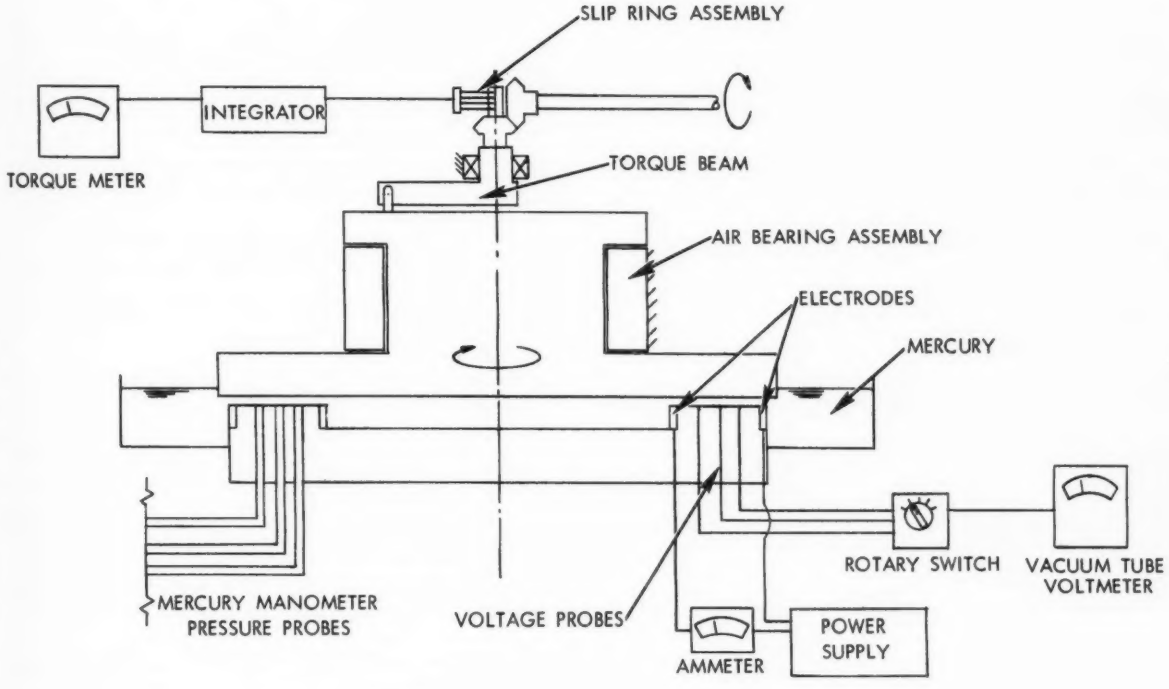


**Figure 2.—Simplified drawing of apparatus.**

# plasma turbulence

**DR. DEMETRIOS G. SAMARAS**
**Directorate of Engineering Sciences, AFOSR**

In nonconducting-fluid dynamics, operation in the turbulent region exhibits a number of advantages. Similar advantages appear in conducting-fluid dynamics since turbulence possesses many beneficial characteristics, such as energy absorption and higher resistivity. In addition, it may suppress and eliminate instabilities.

A number of definitions of turbulence have been given in the past. Invariably, these depend upon the general point of view and the background of the investigator. Nevertheless, it is understood that turbulence appears in fluids and is an irregular motion characterized by random fluctuations of the fluid parameters, such as velocity, density, temperature, concentration, electrical-charge density, and magnetic field.

Turbulence should be differentiated from vortex motions and oscillations which show a regularity, in contrast to the absolute randomness attributed to turbulence. It is said that *the spectrum of turbulence is almost white.*

Experimental evidence suggests that the breakdown of sinusoidal oscillating waves into a small-scale random eddy motion does not take place gradually, but in a sudden and explosive manner. Thus, it is not the gradual development of higher harmonics that changes the instability waves into turbulence, but the sudden appearance of local bursts or spots. These events abruptly change the discrete spectral lines of the original periodic system into a continuous energy spectrum of turbulence.

When turbulence is fully established, every single solenoidal motion (eddy or Fourier component) that composes the total random pattern is stable (damped) for individual infinitesimal disturbances.

The energy source of the turbulent flow (fluctuations) is provided from the mean flow. Thus, the mean flow is subjected to an energy loss which may appear as a pressure drop or friction losses. In an electrically conducting medium, e.g., plasma, the loss appears also as ohmic loss, thus heating the plasma. The energy input flows from the larger to the smaller eddies by nonlinear interaction. When it reaches the smallest eddies, it is dissipated by molecular viscosity and electrical resistivity.

The largest eddies which are responsible for the extraction of the energy from the mean flows have a scale comparable to the size of the equipment. They are many orders of magnitude larger than the smallest eddies which dissipate the energy. It was found that the pressure drop in a turbulent flow does not change with viscosity. In an analogous fashion, the electrical conductivity in a fully turbulent conducting flow is independent of the laminar conductivity and depends only upon the fluctuations (1).

Plasma turbulence may be considered as a hierarchy of eddies of various order similar to the neutral flow turbulence. In plasma turbulence, the total energy may be analyzed into two components: kinetic and magnetic. Thus the energy flows through the entire hierarchy of eddies which are able to transfer energy by nonlinear interaction, both of the same kind, kinetic or magnetic, as well as from one to another, magnetic to kinetic, and vice versa.

In the turbulent flow region, the dissipation forces will not be of a molecular microscopic nature (viscous), as in the laminar, but of a macroscopic nature, i.e., vortices. These damping forces are many times larger than the viscous forces. Their damping influence guarantees the stability of the flow.

When the flow changes from laminar into turbulent, new types of forces (momentum equation) and energy terms (energy equation) appear which drastically transform the external appearance of the flow as well as the internal distribution of forces and energies.

Taking as an example the case of aerodynamics, it is

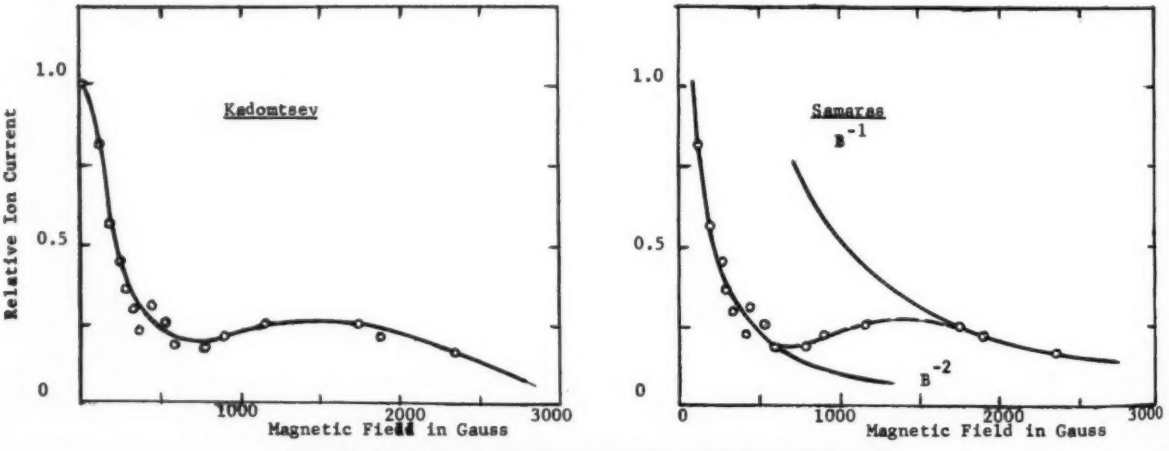


**Figure 1.—Variation of the diffusion current with the magnetic field.**

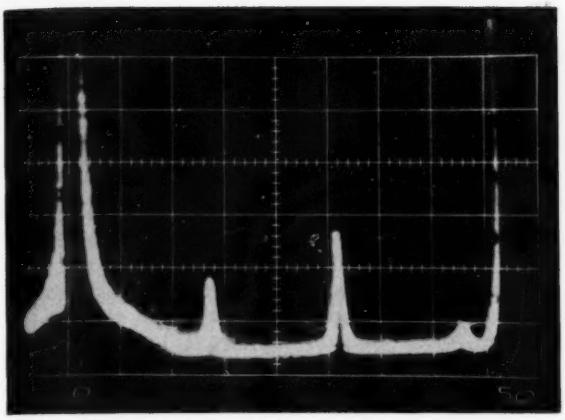

Figure 2a.—Quiet spectrum of potassium plasma.

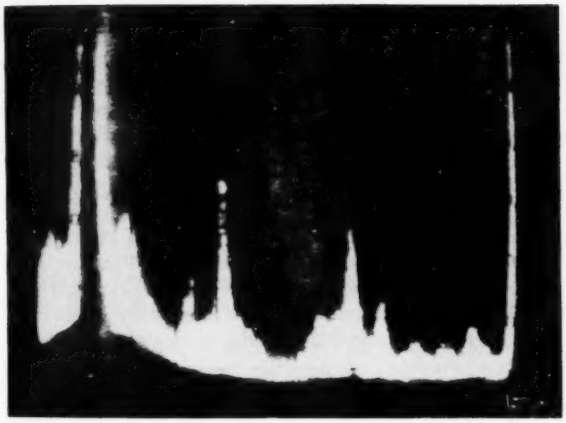

Figure 2b.—Noisy spectrum of potassium plasma.

seen that, in the turbulent flow region, an additional dissipation force appears which corresponds to the so-called Reynolds stresses. Again, an energy dissipation corresponding to these stresses results, which is a large multiple of the viscous energy dissipation. This has a large damping effect upon any fluctuation caused by disturbances.

One of the main losses in a thermonuclear power plant is that caused by the diffusion of plasma through the confining magnetic field (2). In this boundary layer between the plasma and the magnetic field, the magnitude of the diffusion coefficient is of paramount importance because it characterizes the effectiveness of the plasma confinement.

In the past, considerable work has been done on the clarification of the variation of the plasma-diffusion coefficient with the various parameters. Today, there is a strong indication that, in the laminar region, the diffusion coefficient D is inversely proportional to the square of the magnetic field B ($D \propto B^{-2}$), whereas in the turbulent region it is inversely proportional to the magnetic field B($D \propto B^{-1}$). Figure 1 shows the experimental results as originally given by Kadomtsev and later reinterpreted by Samaras (3).

Under AFOSR sponsorship (AF49(638)1546), Drummond and his associates investigated the magnetic turbulence in plasmas by considering it as collision of waves. They arrived at a number of very interesting conclusions. Their turbulence theory describes in detail the time development of the so-called microinstabilities. It applies only to those cases where the instabilities are sufficiently weak (early part of the transition region) and may be regarded as a theory of "weak turbulence."

According to this theory (4), the development of plasma turbulence can be broken roughly into four time phases:

a. During the first phase, the linearized theory applies and the unstable waves grow exponentially.

b. In the second phase, the so-called "quasilinear" theory applies and the background particle distribution diffuses in such a way as to bring the growth rate of the unstable waves to zero, thus leaving a quasistationary spectrum of waves.

c. In the third phase, the waves in the quasistationary spectrum interact in such a way as to distort the spectrum and also keep the energy in the spectrum roughly constant.

d. In the fourth phase, the waves interact to produce "virtual" waves which, in turn, lose energy to the bulk of the particles by Landau damping. This "nonlinear Landau damping" produces a slow decay of the wave energy (energy falls off in inverse proportion to time) and a slow heating of the plasma, together with a diffusion of the plasma across the magnetic field until all the wave energy has been given up to the particles and the plasma is in a quiescent, stable state.

The first two phases can be fairly well separated in time, whereas the third and fourth occur roughly simultaneously.

In addition to the aforementioned theoretical work, experimental work is in progress to substantiate these conclusions.

Interesting work on electromagnetic turbulence is being performed by Professor N. C. Jen, City College of New York, under AFOSR sponsorship (AF-AFOSR-1093-67). At low magnetic fields he obtained pictures indicating monochromatic (plasma) oscillations, (fundamental and harmonics). With an increase of the magnetic field, the spectrum of the oscillations spreads out, showing a tendency to become white (3 & 5). This change of the plasma oscillations into magnetic turbulence may be seen in Figure 2. A detailed account of Professor Jen's work will be published soon.

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**AFOSR**

# the characterization of liquid structure

Significant technological benefits would obviously be derived from an improved understanding of the liquid state of matter. Endless examples could include not only direct applications but indirect ones as well. Most engineering materials inevitably pass through the liquid state on the path from raw material to finished product.

The goal of any theory of liquids must be to understand and predict the macroscopic properties (e.g., viscosity, compressibility, heat capacity, boiling and freezing point) in terms of the microscopic properties (the configuration of component atoms and the forces between them). Such interpretations have been attempted by a variety of theoretical models, but none of these can claim other than limited success.

The idealized limits which real systems approach assist in the interpretation of the solid and gaseous states. These are conditions of complete order (for solids) and complete disorder (for gases). No such convenient comparison is to be bound for liquids. This situation has been admirably described by E. A. Moelwyn-Hughes:

> "The liquid state of matter is thus an intermediate one. Like a central party in politics or a moderate denomination in religion, it is less rigorously defined and more difficult to understand than either of the extremes that flank it."

In this most fundamental area the Directorage of Chemical Sciences, AFOSR, has long sponsored selective research efforts. These have included theoretical as well as experimental contributions.

The theoretician requires for his purposes the most accurate and extensive experimental data for test and evaluation. The necessary experimental approach is emphasized in the diverse activities of Professor C. J. Pings, California Institute of Technology, in the AFOSR Program for Research on Liquid Structure. Some recent developments in this Program will be described here.

Liquid argon is an atomic liquid held together by dispersion forces (van der Waals attraction). As such, it is a favorite of theoreticians seeking success with a relatively simple system before proceeding to more complex structures and bonding forces.

Employing X-ray diffraction measurements, Professor Pings and coworkers have investigated the structure of argon at 13 separate states of temperature and pressure in the general critical region (143°-163°K, 40-98 atmospheres). These states were carefully selected so as to fall on a grid of lines of constant density and temperature. For the first time, the independent influences of these 2 variables were delineated.

The structural description is made in terms of the net radial distribution function, G(r). This function reveals the variation in local density (relative to the average value) as a function of distance, *r*, from the center of an arbitrary reference atom in the fluid. G(r) is determined by computation, through a Fourier transform, based on the experimentally measured intensities of scattered X rays as a function of angle.

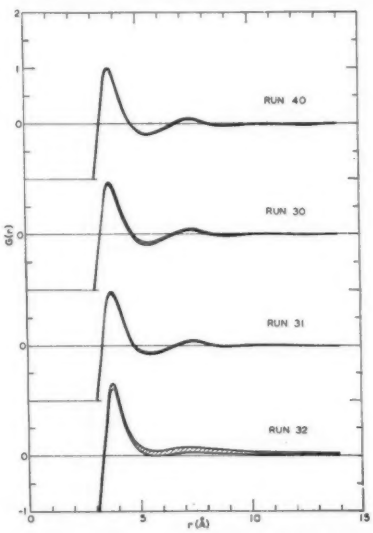


**Figure 1.—The atomic radial distribution function of argon at t = -125°C. Run 40, $\bar{\rho}$ = 0.982 g/cc; Run 30, $\bar{\rho}$ = 0.910 g/cc; Run 31, $\bar{\rho}$ = 0.780 g/cc; Run 32, $\bar{\rho}$ = 0.280 g/cc.**

Representative examples of the results, in Fig. 1, show G(r) at various densities. As seen, the probability of finding a neighboring atom is a damped, cyclic function of distance; at small enough distances (because of interatomic repulsion), this probability is zero (G(r) = -1).

Based on this study, the structural features of argon are regarded as predominantly related to the sample density. The density influence on the longer range order can be seen in Figure 1. Also, in the present curves, subpeaks reported in previous investigations are absent. These irregularities, to which special structural features had been ascribed, are now believed to have been due to experimental error as well as to computational difficulties. However, even with more modern detection systems and data-processing methods, the recent results still retain some notable uncertainty (indicated by the shaded areas).

Another important contribution by the Cal-Tech program is represented by efforts to compute the interatomic potential energy function, U(r), from the data obtained for the radial distribution function. This analysis is based on the previously developed expansion of G(r) in a power series involving the density and the Mayer cluster integrals. By neglecting terms higher than first order, with iterative computational techniques, the result shown in Figure 2 was obtained. It is regarded as in good agreement with currently accepted estimates. However, the data used were appropriate to densities about one half the critical value. The neglect of second-order terms in the expansion is hardly realistic.

In future efforts, using more extensive data obtained in a selected density range, it should be possible to include second-order terms and obtain an improved potential-energy curve without relying on an iterative procedure.

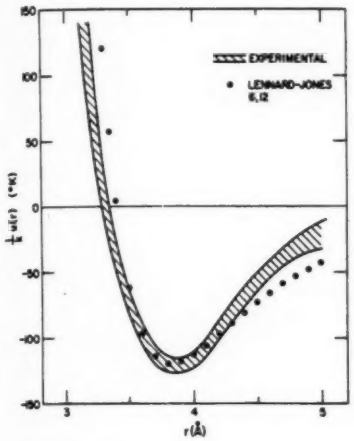


**Figure 2.—Intermolecular potential function for argon. The shaded area represents uncertainty arising from the experimental determination of the radial distribution function.**

In the past, using the above-mentioned series expression for G(r) in terms of U(r), radial distribution functions have been derived from assumed approximations to the potential-energy curve. However, the efforts of Professor Pings are apparently the first aimed in the opposite direction, employing experimentally determined radial distribution functions.

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# PROBING THE ELECTROJET

## UPPER ATMOSPHERE PHYSICS LABORATORY, AFCRL

The equatorial electrojet is an electric current of about 90,000 amperes flowing in about 110-km altitude along the geomagnetic equator during daylight hours. It has a cross-section width of about 600 to 1,200 km, and a thickness of 10 to 20 km. Its existence was suspected in the last century from magnetic recordings before the ionosphere had been discovered. The first direct evidence was obtained in 1949 by Elwood Maple (then of the Naval Ordnance Laboratory, but now at AFCRL) using a rocket-borne magnetometer.

The electrojet is part of a current system of global dimensions flowing in ionospheric altitudes. The currents are driven by a dynamic effect involving the earth's magnetic field and resulting from tidal motions of the upper atmosphere. Although the existence of the electrojet as a repetitive diurnal phenomenon is well-documented, its dynamical behavior—that is, its variations under the varying influences of solar radiation, solar wind, and so on—is poorly understood. One of AFCRL's experimental approaches is to use a highly instrumented KC-135 aircraft which has collected much data on the equatorial electrojet over the past several years. The investigations are under the direction of Dr. George J. Gassmann.

It has been known from ground observations at the geomagnetic equator that the overhead current density varies considerably from day to day and season to season, and that it decreases with increasing magnetic activity (solar wind). But little was known concerning the over-all width of the electrojet and its changes during a single day. With instrumented aircraft, researchers can cross the electrojet in about 100 minutes to obtain a north-south cross section. This time is sufficiently short, except during magnetically disturbed days, to assure that temporal changes are not superimposed on the spatial changes. The obtained cross sections could therefore be considered as quasi-instantaneous.

To gather the data, the AFCRL KC-135 was flown at an altitude of about 11 km covering about 12 degrees of latitude along a particular magnetic meridian. Two areas were chosen, one over Peru and one over the Pacific Ocean. The aircraft carried a magnetometer which recorded the magnetic-field intensity. This recorded magnetic-field intensity will, of course, not only include that induced by the electrojet current, but also other magnetic fields, such as that of the magnetosphere. A separation of these components was achieved by flying identical routes during both day and night. From the data, plots of electrojet cross sections were derived. In addition to the data on magnetic cross sections, other data on electron density and the power of back-scattered radio signals were obtained using an airborne ionospheric sounding system (type Granger 3900). These sets of data are of supplementary value since one is related to the existing conductivity, and the other indicates the state of turbulence in the altitude of the electrojet.

Other effects observed were:

1) During periods of high geomagnetic activity, the width and shape of the electrojet cross section change from hour to hour, while little change occurs during low geomagnetic activity.

2) Striations or bands of higher and lower current density were found within the electrojet, spaced several hundred km apart. During quiet magnetic activity, these did not change position for several hours. No striations in E-layer electron density were found. In the light of the theory of the formation of the electrojet current, this experimental finding permits conclusions to be drawn as to the relative stability of electric fields in the magnetosphere near the earth.

3) During the May 30, 1965 solar eclipse in the Pacific when the moon's shadow crossed the magnetic equator, the electrojet left its normal position along the magnetic equator (dip angle is zero degrees) and temporarily shifted by about 300 km. A fast recovery from this anomalous position was made after the eclipse. This recovery indicates that the electric fields associated with the electrojet are able to reassemble within less than 2 minutes.

# space and time asymmetries in particle physics

DR. C. P. POIRIER, General Physics Research Laboratory, ARL

During the past decade, 3 apparent symmetries of nature have come increasingly under examination. Up until 10 years ago, invariance under charge conjugation C (which reverses the sign of all charges) and parity P (which mirrors right into left) was unquestioned. Then experiments first carried out in 1956, following the proposals of Lee and Yang (1), showed that the weak interaction (which is responsible for nuclear $\beta$-decay and the decay of certain unstable particles) is not invariant either under mirror reflection of the spatial coordinates or with respect to charge conjugation.

Symmetry was soon restored by theorists who suggested that the product of C and P was conserved instead. This appeared true in each case of separate C and P violation; the symmetry rules were restored if the terms "right" and "left" were interchanged and if, at the same time, each particle was replaced by its antiparticle. However, in 1964 a meson decay reaction, specifically $K_2^\circ \rightarrow \pi^- + \pi^+$, strictly forbidden by CP conservation, was observed actually to occur. The nonconservation of CP in this reaction implies that the third symmetry of nature, time-reversal invariance T, may also be violated by the weak interactions. To see why this reaction indicates apparent T violation, we must examine the famous CPT theorem and the reasons why the decay $K_2^\circ \rightarrow \pi^- + \pi^+$ is strictly forbidden by CP conservation.

The CPT theorem, first stated by Luders and Pauli (2), specifies that in any normal physical theory an event must be invariant under the successive application of all three operators, C, P, and T, applied in any order. Stated simply it means that, as much as the separate violations of C, P, and T in any interaction may insult one's intuition, they do not contradict any of the basic axioms underlying the structure of relativistic quantum field theory, provided that the product operation CPT is invariant. We cannot go into the basic axioms here, but it is sufficient to say that this result is required by special relativity.

The neutral K-mesons are very remarkable particles; the properties they exhibit are very unusual by the standards of classical physics and can be satisfactorily interpreted only by quantum theory. Neutral K-mesons exist in two states: $K^\circ$ and $\overline{K}^\circ$, neither of which is invariant under the CP-operation. The operator C interchanges the $K^\circ$ and $\overline{K}^\circ$, while the P-operation multiplies the state by a factor $(-1)^p$, where p is the intrinsic parity of the K-meson. However, since the intrinsic parity of any particle is defined relative to some arbitrarily chosen standard, we can choose the K-meson to be a pseudoscalar particle and write the following two relations:

$$CP|K^\circ> = -|\overline{K}^\circ>$$

$$CP|\overline{K}^\circ> = -|K^\circ>$$

Experimentally, it has been observed that approximately 50% of a neutral K-beam decays into the two-pion state, $\pi^+ + \pi^-$. A little study shows that this state is invariant and even under the CP-operation. C just interchanges the $\pi^+$ and $\pi^-$, making this state even under C. The parity of the state is $(-1)^\ell$, where $\ell$ is the relative orbital angular momentum between the $\pi^+$ and $\pi^-$. $\ell$ is known to be zero making this state one of even parity. We are now faced with a dilemma—a particle state not invariant under the CP-operation decaying into a state which is invariant. This result led Gell-Mann and Pais (3) to suggest that the neutral K-mesons are really particle-mixture states, that is, mixtures of states which are invariant under CP. Thus, if we define

$$CP|K_1^\circ> = |\overline{K_1^\circ}> \text{ (even state)}$$

$$CP|K_2^\circ> = -|\overline{K_2^\circ}> \text{ (odd state),}$$

we can construct the two states $K^\circ$ and $\overline{K}^\circ$ as follows:

$$|K^\circ> = 1/\sqrt{2}\,(|K_1^\circ> + |K_2^\circ>)$$

$$|\overline{K}^\circ> = 1/\sqrt{2}\,(|K_2^\circ> - |K_1^\circ>)$$

There is a considerable body of experimental evidence to indicate that this interpretation of the neutral K-meson is correct.

It follows from these definitions that a neutral K-meson beam has a 50% chance to decay as a $K_1^\circ$-meson, and 50% chance to decay as a $K_2^\circ$-meson. The two-pion decay mode of the neutral K-meson beam can be understood as the decay of the $K_1^\circ$-meson. The interaction is invariant under CP, as both the initial state ($K_1^\circ$) and the final state ($\pi^+ + \pi^-$) are even under CP. On the other hand the $K_2^\circ$, being odd under CP, is strictly forbidden to decay into 2 pions if CP is to be conserved.

The reasoning behind our earlier statement that the existence of the decay $K_2^\circ \rightarrow \pi^+ + \pi^-$ indicates T violation should now be clear: remembering that the CPT theorem specifies that any event must be invariant under the product operation CPT, then the CP-violating $K_2^\circ$ decays imply that time is not reversible in the interaction.

The question now is how to explain this phenomenon. Four classes of theories have been proposed to explain the origin of the CP violation:

1. The CP violation occurs in the weak interaction.

2. Although the weak interaction conserves CP, there is a new interaction, which violates C and T invariance, and is $10^{10}$ times as strong as the usual weak interaction.

3. The electromagnetic interaction strongly violates both C and T invariance; this shows up as a small CP violation in $K_2^\circ$ decay.

4. There is a superweak interaction which is $10^{-9}$ times weaker than the usual weak interaction. The interaction violates CP, but is so weak that it can be observed experimentally only with K-mesons.

Recent experimental results on

the decay of the K-meson seem to rule out all theories in class 4, and a subgroup of theories in class 1. Theories still to be checked by experiment are those in classes 2 and 3, and those remaining in class 1.

In closing, we may say that particle physics has been the graveyard of commonsense views of space and, perhaps, of time. The startling disclosure that empty space is not necessarily the "same" in all directions, and that time flowing backwards may not have the same properties as the forward flow of time, may have a profound effect on classical physics. If, for example, time symmetry is indeed violated, the blow will land on all our conventional approaches to the condition of equilibrium in thermodynamic systems.

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# new molecular-beam generator

**OPTICAL PHYSICS LABORATORY, AFCRL**

A powerful and unique new facility for studying the chemistry, bonding, energies, and dissociation processes of interacting gas molecules has been placed in operation at AFCRL. The facility is a molecular-beam generator operating in the energy range of 1 to 10 electron volts, and producing a beam intensity in excess of $10^{18}$ molecules per square centimeter per second.

Dr. A. T. Stair, Jr., and his associates at AFCRL designed the facility and will use the molecular-beam generator to study atomic and molecular interactions in a manner analogous to the use of cyclotrons and synchrotrons in particle physics. Accelerating a high intensity beam of atoms and molecules to a few electron volts, however, has proved more difficult than accelerating electrons and ions to energies of millions of electron volts.

But it is within this lower energy range that most familiar chemical reactions take place—the simple oxidation of metals, chemical changes in the atmosphere, the release of stored energy in fuels, and so on. The bond strengths of molecules and the activation energies of chemical reactions lie within the 1- to 10-ev energy range.

The heart of the new AFCRL facility, a large evacuated chamber ($10^{-7}$ to $10^{-8}$ torr), has about the size and shape of a railroad tank car. It measures around 5 feet in diameter and is about 15 feet long. Intersecting this evacuated tank to form a T configuration is another cylindrical chamber where the primary beam is generated. The entire apparatus is evacuated by 3 large vacuum pumps.

Before the AFCRL facility was designed, Stair and his co-workers, F. Hushfar, J. Rogers, and R. Murphy, studied the few possible techniques for accelerating an intense beam of molecules to high velocity. The most promising technique is to use a supersonic nozzle in which a high-pressure gas on one side of an orifice expands isentropically into a vacuum. The flow field in front of the jet nozzle has an ellipsoidal distribution. This is because in

supersonic expansion high Mach numbers are reached and gas particles attain a velocity in the axial direction higher than their thermal velocities.

To define the beam—that is, to remove all particles except those traveling in the axial direction—a skimmer is used. The skimmer is nothing more than a cone-shaped aperture placed in front of the beam, with the hole at the tip of the cone facing the nozzle. Gas expansion has already taken place and free molecular flow has been established before the gas passes through the skimmer into the evacuated main tank. There the beam is modulated by means of a chopper, which cuts the beam into short segments by rotating a disk with slots arranged on its periphery.

For gas-gas collision experiments, a second supersonic nozzle-skimmer arrangement is used to fire a molecular beam at right angles to the main beam. If the initial state of each beam is known, the reactive collisions that result could provide answers to some of the fundamental questions of molecular chemistry and physics. What new products are formed? What is the dependence of the reaction upon the relative velocity of the collision and internal energy states of the particles? How is the energy distributed among the collision partners? What sort of radiation is emitted? The answers to these questions could lead to more efficient fuels and engines, to an understanding of the dynamic chemistry of the upper atmosphere, and perhaps to the control of pollution of the atmosphere.

The study of gas-surface interactions—the second field of molecular-beam research—can provide new empirical data on the processes that take place when high-velocity gas molecules impinge on a surface. Apart from chemical interactions, how high velocity particles bounce off surfaces is not at all clear. Do particles bounce off at random or in some preferential manner depending on their velocity? Such data are needed for calculations pertaining to lift and drag forces on vehicles at high altitude which, in turn, enter into the calculations of satellite orbit decay.

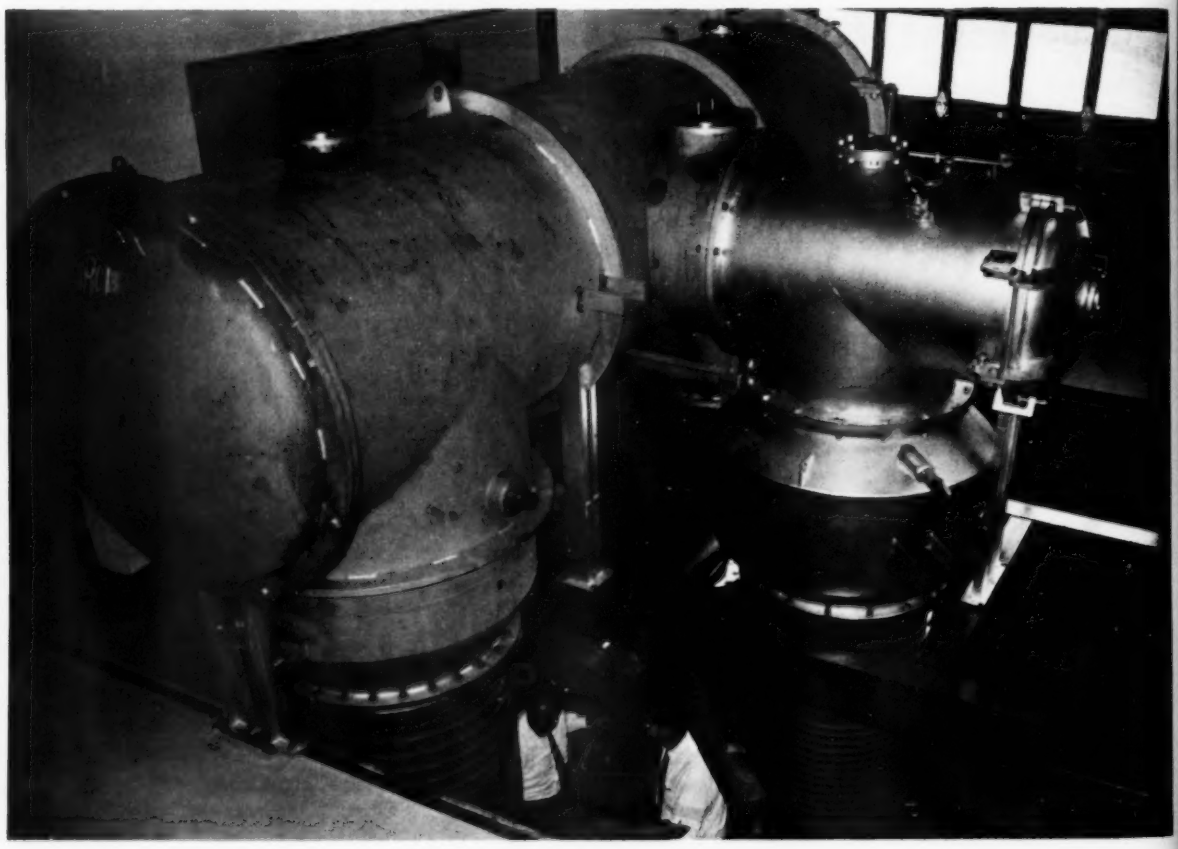

**Figure 1.—AFCRL's molecular-beam generator.**

GPO 861-741